

DIVERGENT VALIDITY OF THE WECHSLER MEMORY SCALE – FOURTH EDITION
(WMS-IV) AND THE DELIS-KAPLAN EXECUTIVE FUNCTION SYSTEM (D-KEFS)

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ABSTRACT

The present study examined the relationship between memory and executive functioning in a college student population using the *Wechsler Memory Scale, Fourth Edition* (WMS-IV) and selected tests from the *Delis-Kaplan Executive Function System* (D-KEFS). Contrary to results of previous research on the relationship between measures of memory and executive functioning in clinical populations, results of canonical correlation analyses used in the present study do not suggest there is a significant degree of shared variance between WMS-IV subtests and D-KEFS Trail Making Test and Color-Word Interference Test variable sets in a college student sample. Simple correlation analyses, however, suggest aspects of memory and executive functioning are weakly to moderately related. Given that there was not a significant degree of shared variance between the WMS-IV and D-KEFS tests, results of the present study suggest the WMS-IV and D-KEFS Trail Making Test and Color-Word Interference Test have adequate divergent validity and are useful for differential diagnosis of neuropsychological conditions. Given that results of the present study are inconsistent with results of previous studies, it is possible the relationship between measures of memory and executive functioning differs in clinical vs. nonclinical populations. Further research is needed to clarify the role of attention and other variables in the relationship between memory and executive functioning.

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TABLE OF CONTENTS

ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iii
LIST OF TABLES AND FIGURES.....	viii
CHAPTER I: INTRODUCTION.....	1
Overview.....	1
Memory.....	5
Executive Function.....	6
Rationale and Significance of the Study.....	7
Research Questions and Hypotheses.....	13
CHAPTER II: REVIEW OF THE LITERATURE.....	18
Overview.....	18
Memory.....	20
Neuroanatomical Correlates of Memory.....	22
Measurement of Memory.....	27
Executive Functioning.....	29
Neuroanatomical Correlates of Executive Functioning.....	33
Measurement of Executive Functions.....	38
The Relationship between Memory and Executive Functions.....	43
Importance of Research with Neurotypical Populations.....	45
Conclusion.....	46

CHAPTER III: METHOD.....	47
Participants.....	47
Procedures.....	48
Measures.....	49
Statistical Procedures.....	54
Description of the Sample.....	57
CHAPTER IV: RESULTS.....	62
Results and Analyses.....	62
Descriptive Statistics.....	62
Statistical Assumptions.....	68
Canonical Correlation.....	72
Summary.....	73
CHAPTER V.....	76
Summary of the Study.....	76
Discussion and Implications of the Relationship between Memory and Executive Functioning.....	80
Discussion.....	80
Implications.....	88
Delimitations and Limitations of the study.....	94

Delimitations.....	94
Limitations.....	95
Directions for Further Research.....	97
Conclusion.....	98
REFERENCES.....	100

LIST OF TABLES AND FIGURES

Table 1

WMS-IV Subtests and D-KEFS Conditions included in Canonical Correlation Analysis #156

Table 2

WMS-IV Subtests and D-KEFS Conditions included in Canonical Correlation #256

Table 3

Descriptive Statistics for the Sample58

Table 4

Medical/mental health diagnoses of participants at the time of participation in the study59

Table 5

Medications/supplements reported by participants at the time of participation in the study60

Table 6

Means and Standard Deviations for the WMS-IV and D-KEFS63

Table 7

Correlations between WMS-IV Subtest Scores and D-KEFS Condition Scores67

Figure 169

Figure 269

Figure 370

Figure 471

Figure 571

Figure 672

CHAPTER I

INTRODUCTION

Overview

Although neuropsychological assessment has been a primary focus of the practice of clinical neuropsychology since its inception, there has been an upward trend in the amount of time clinical neuropsychologists devote to assessment (as compared to psychotherapy, training, research teaching, rehabilitation, service, consultation, and administration) in the past ten years (Rabin, Barr, & Burton, 2005; Rabin, Paolillo, & Barr, 2016). Results of survey data from clinical neuropsychologists in 2005 suggest 95.7% of clinical neuropsychologists devoted 42% of their time on average to neuropsychological assessment (Rabin et al., 2005); however, approximately ten years later, 98.8% of neuropsychologists surveyed reported spending 59.2% of their time on neuropsychological assessment (Rabin et al., 2016). These statistics indicate assessment remains a cornerstone of the field of neuropsychology and an important area for further research.

Although assessment has a long history as an important domain of practice in the field of clinical neuropsychology; it has changed rather significantly over the years in terms of the tests used and the range of cognitive domains assessed. In their review of assessment practices of clinical neuropsychologists, Rabin and colleagues (2005) report that, “while the overall pattern of survey findings from the 1930s through the 1970s reveals that intelligence and projective tests dominated psychological testing, some early surveys included a small number of neuropsychological instruments” (p. 34). As the field of clinical neuropsychology developed further in the 1980s and 1990s, assessment of intelligence (specifically the Wechsler Intelligence

DIVERGENT VALIDITY OF THE WMS-IV AND D-KEFS 2

Scales [WIS]) remained a cornerstone of neuropsychological evaluations; however, additional domains of neuropsychological functioning were assessed more routinely. This change in the field was illustrated by surveys of practitioners involved in neuropsychological assessment in the 1980s (Butler, Retzlaff, & Vanderploeg, 1991; Guilmette, Faust, Hart, & Arkes, 1990).

Guilmette and colleagues surveyed a range of psychologists who reported practicing neuropsychology “to at least some degree” (p. 375), and combined information about their frequency of test usage with information from an earlier study (i.e., Hartlage & Telzrow, 1980) to create a ranked list of the assessments most frequently used in neuropsychological evaluations. The top five tests ranked included measures of intelligence, memory, executive functioning, psychiatric symptoms, and academic achievement.

Another research team, Butler and colleagues (1991), compiled a list of 116 tests based on tests referred to in three journals (i.e., the *Journal of Clinical and Experimental Neuropsychology*, the *International Journal of Clinical Neuropsychology*, and *Neuropsychologia*) between 1985 and 1989. They then provided this list of tests to members of the International Neuropsychological Society and asked respondents to indicate which assessments they used with most patients. Survey results suggests tests from a variety of domains (e.g., memory, executive function, psychomotor function, visuospatial ability, speech/language, and personality) were frequently used by members of the International Neuropsychological Society.

According to Rabin et al. (2005), the top five neuropsychological assessment measures used by clinical neuropsychologists surveyed in 2001 were the *Wechsler Adult Intelligence Scale, Revised* (WAIS-R; Wechsler, 1981)/*Wechsler Adult Intelligence Scale, Third Edition*

DIVERGENT VALIDITY OF THE WMS-IV AND D-KEFS 3

(WAIS-III; Wechsler, 1997a), the *Wechsler Memory Scale, Revised* (WMS-R; Wechsler, 1984)/*Wechsler Memory Scale, Third Edition* (WMS-III; Wechsler, 1997b), the *Trail Making Test* (TMT; Reitan, 1992; Reitan & Wolfson, 1993), the *California Verbal Learning Test* (CVLT; Delis, Kramer, Kaplan, & Thompkins, 1987)/*California Verbal Learning Test, Second Edition* (CVLT-II; Delis, Kaplan, Kramer, & Ober, 2000), and the *Wechsler Intelligence Scale for Children, Third Edition* (WISC-III; Wechsler, 1991). In an updated survey by Rabin and colleagues (2016), clinical neuropsychologists who were surveyed in 2011 reported the same (or updated iterations of the same) top five assessment measures identified in the Rabin et al. (2005) survey: the *Wechsler Adult Intelligence Scale, Fourth Edition* (WAIS-IV; Wechsler, 2008), the *Wechsler Memory Scale, Fourth Edition* (WMS-IV; Wechsler, 2009a), the TMT (Reitan, 1992), the CVLT-II (Delis et al., 2000), and the *Wechsler Intelligence Scale for Children, Fourth Edition* (WISC-IV; Wechsler, 2003). Rabin et al. (2016) state that a key difference in the rankings from the 2016 survey as compared to the 2005 survey is that the *Delis-Kaplan Executive Function System* (D-KEFS, Delis, Kaplan, & Kramer, 2001a) is now ranked as the sixth most frequently used measure by neuropsychologists.

As comprehensive neuropsychological evaluations assess a wide range of neurocognitive domains, it is important that neuropsychological evaluations include measures that are sensitive to dysfunction and have the specificity to identify particular areas of neurocognitive deficit. Lezak, Howieson, Bigler, and Tranel (2012) define test sensitivity as, “the proportion of people with the target disorder who have a positive result,” and test specificity as, “the proportion of people without the target disorder whose test scores fall within the normal range” (p. 127). A positive result on a test with high sensitivity is a score at a level which suggests the presence of

neurocognitive dysfunction. Tests with high sensitivity are useful as screening measures because they help neuropsychologists determine whether neurocognitive dysfunction is present, but they do not provide information regarding which particular functions are impaired. In contrast, tests with high specificity give neuropsychologists the precision they need to identify which areas of neuropsychological functioning are impaired. Therefore, it is important that tests designed to measure specific neuropsychological constructs do not also inadvertently measure other constructs.

Ongoing research is important to evaluate the construct validity of frequently used neuropsychological assessments. Raykov and Marcoulides (2011) define construct validity as, “the extent to which an instrument assesses a construct of concern” (p. 190); gathering evidence of construct validity for an assessment involves examining relationships between constructs, measures of those constructs, and real-world applications of those constructs. Convergent and divergent validity are two types of construct validity often examined in test validation. Evidence of convergent validity helps determine whether an assessment measures similar constructs as other assessments meant to measure the construct (i.e., a memory test correlates with other well-validated memory tests), whereas evidence of divergent validity helps ensure an assessment measures a different overarching construct (i.e., a memory test should not be highly related to a measure of executive functioning). Statistically, construct validity is often evaluated using variations of correlation analysis, factor analysis, latent variable modeling, and the multitrait-multimethod (MTMM) matrix approach (Raykov & Marcoulides, 2011). Assessments with strong evidence of construct validity can be interpreted more confidently than assessments with weak evidence of construct validity because practitioners can be more confident that the

assessment measures the construct it was designed to measure.

Given the nature of referral questions in the field of neuropsychology, practitioners in the field of neuropsychology need to have confidence that the measures they use to inform high-stakes decisions have strong evidence of validity. Neuropsychologists routinely receive referrals from other professionals in which they are asked to make diagnoses with lifelong implications, provide information about patient prognosis to facilitate treatment planning or educational planning, provide information to be used for disability determination, or determine whether a patient has the capacity to work, live independently, stand trial, etc. (Rabin et al., 2016).

Construct validity of neurocognitive measures is also important in the field of neuropsychology given how neuropsychologists use assessment results to inform diagnosis and clinical recommendations. Neuropsychologists analyze patterns of performance on a battery of assessments to determine which neurocognitive abilities are intact and which are impaired. For this process to be effective, the assessments given as part of the evaluation must have adequate construct validity.

The present study aims to evaluate construct validity of two commonly used measures of memory and executive functioning. Prior to discussing key studies on the relationship between executive functioning and memory and the need for ongoing validation of measures of memory and executive functioning, the two domains are defined and discussed separately.

Memory

Memory has been defined as an “indicator that learning has previously occurred” (Wechsler, 2009b, p. 1); that is, memory is required to demonstrate prior learning. At its most basic level, memory can be conceptualized as declarative (i.e., explicit) or non-declarative (i.e.,

implicit). Declarative memory is an individual's ability to remember facts and events (Squire & Zola, 1996; Eichenbaum, 2000; Eichenbaum, 2004). Semantic memory and episodic memory are both types of declarative memory. Non-declarative or implicit memory involves procedural or skill-based memory (i.e., remembering how to operate a microwave, drive a car, etc.).

Research supports the conceptualization of declarative memory in three stages: sensory memory, immediate memory, and long-term memory (Parkin, 2001; Lezak et al., 2012). Measures of memory often further delineate declarative memory as either auditory or visual; the WMS-IV has a three-factor structure which includes an auditory memory factor, a visual memory factor, and a visual working memory factor (Hoelzle, Nelson, & Smith, 2011).

Executive Function

There has been some debate as to what the term 'executive functioning' encompasses. Executive functioning was initially thought of as a unitary cognitive process (Baddeley, 1990); however, more recent research suggests executive functioning is better conceptualized as several processes. According to Jewsbury, Bowden, and Strauss (2016), the only replicated factor model of executive functioning is Miyake, Friedman, Emerson, Witzki, Howerter, and Wager's (2000) switching, inhibition, and updating model. This model suggests the executive functions of switching, inhibition, and updating are unified under the umbrella of 'executive functioning' but distinct from one another.

Current definitions of executive functioning support the conceptualization of executive functioning as a group of unified, but diverse cognitive processes. Miyake and Friedman (2012) define executive functioning as, "a set of general-purpose control mechanisms, often linked to the prefrontal cortex of the brain, that regulate the dynamics of human cognition and action" (p.

8). Similarly, Lezak and colleagues (2012) define executive functioning as the cognitive abilities that are necessary for a person to adaptively respond to novel or complex situations through intentional, self-directed behavior, planning and decision-making. More recently, Friedman and Miyake (2016) defined executive functions as, “high-level cognitive processes that, through their influence on lower-level processes, enable individuals to regulate their thoughts and actions during goal-directed behavior” (p. 1). Each of these definitions conceptualize executive functioning to be a set of distinct but related processes which involve regulation and adaptation.

Given the diverse array of executive functions to be measured, some researchers have claimed there cannot be a ‘gold standard’ measure of executive functioning (Royall et al., 2002); however, some measures are more popular than others. The most commonly used measure of executive function in 2005 was the *Wisconsin Card Sorting Test* (WCST; Heaton, 1981; Rabin et al., 2005). Currently, the most commonly-used measures of executive function are the WCST (Heaton, 1981)/the *Wisconsin Card Sorting Test – 64 card version* (WCST-64; Heaton, Chelune, Talley, Kay, & Curtiss, 1993), the TMT (Reitan, 1992), and the D-KEFS (Delis et al., 2001a). While the WCST and the TMT measure different aspects of executive function (i.e., concept formation/abstract reasoning and set shifting, respectively), the D-KEFS includes nine tests which each measure components of executive function including verbal fluency, inhibition, set shifting, concept formation and abstract reasoning, task switching, etc.).

Rationale and Significance of the Study

As mentioned above, ongoing research is needed to validate the measures commonly used in neuropsychological evaluations. Raykov and Marcoulides (2011) state that researchers can evaluate construct validity of assessments by examining relationships between measures of

theoretically similar and dissimilar constructs. Recent research has used canonical correlation analysis to examine the relationship between broad domains including intelligence and executive functioning (Davis, Pierson, & Finch, 2011; Roberds, 2015; Piehl, 2016), cognitive and executive functioning and academic achievement (Hernández Finch, Speirs Neumeister, Burney, & Cook, 2014), and cognitive functioning and sensory-motor functioning (Davis, Pass, Finch, Dean, & Woodcock, 2009; Masur-Mosiewicz, 2012; Stankovic & Popovic, 2012). Earlier research also used canonical correlation analysis to examine the relationship between intelligence, memory, and motor functioning (Fowler, Macciocchi, & Ranseen, 1986).

The purpose of the present study is to examine the relationship between memory and executive functioning to further clarify the relationship between these two domains. Past research suggests a relationship between certain aspects of memory and executive functioning. For example, results of one exploratory study by Vanderploeg, Schinka, and Retzlaff (1994) suggest that aspects of executive function are associated with verbal learning and working memory. Specifically, Vanderploeg et al. (1994) found that data from the CVLT, the WAIS-R, the TMT Part B (TMT-B), the WCST, and the *Multilingual Aphasia Examination* (Benton & Hamsher, 1983) contributed to one significant canonical correlation. CVLT verbal learning and working memory scores as well as TMT-B scores and WAIS-R Digit Span contributed most to the canonical variate. Vanderploeg et al. (1994) suggest the results of this study support the conclusion that working memory and delayed memory are interdependent constructs, both of which are related to attention and executive functioning.

Tremont, Halpert, Javorsky, and Stern (2000) further examined the relationship between memory and executive functioning using several measures including the WMS-R Logical

Memory I and II subtests, the CVLT, the ROCFT, the WCST, the *Controlled Oral Word Association Test* (COWAT; Benton & Hamsher, 1989), and the TMT-B. Tremont and colleagues defined participants with significant executive dysfunction as those who had two to three measures of executive functioning in the impaired range. Results suggest significant executive dysfunction is associated with poorer verbal learning, verbal immediate recall, and verbal delayed recall as measured by the CVLT; however, there was not a statistically significant relationship between executive functioning measures and story recall (i.e., WMS-R Logical Memory performance). Tremont and colleagues (2000) conclude that people with poorer executive functioning abilities are likely to struggle more with encoding and storing verbal information that requires examinees to semantically structure seemingly disorganized information to aid in later recall. Results of this study suggest attention and set shifting have a differential relationship with verbal list learning and story recall. Tremont et al. (2000) state, “these findings argue for the inclusion of both verbal list learning and story recall [tasks] in a comprehensive neuropsychological evaluation to separate the indirect effects of frontal system dysfunction on learning and memory from direct memory dysfunction” (p. 299).

Another study by Duff, Schoenberg, Scott, and Adams (2005) used four canonical correlation analyses to examine the relationship between learning, memory, and executive functioning. Using results of several measures of memory and executive functioning from over 200 patients referred for neuropsychological evaluations for a wide range of presenting conditions (e.g., head injury, brain tumors, dementia, depression, pain disorders, etc.), Duff and colleagues examined the relationship of executive functioning measures with verbal memory measures, visual memory measures, immediate memory measures, and delayed memory

measures. Executive functioning measures included the WCST (Heaton, 1981), the *Halstead Reitan Trail Making Test Part B* (TMT-B; Reitan & Wolfson, 1993), the COWAT (Benton & Hamsher, 1989), and the Similarities subtest of the WAIS-R. Memory measures included the WMS-R (Wechsler, 1987), the ROCFT delayed recall condition (Rey, 1941), and the *Rey Auditory Verbal Learning Test* (RAVLT; Rey, 1941; Rey, 1964).

Each of the four canonical correlation analyses (i.e., executive functioning measures/verbal memory measures, executive functioning measures/visual memory measures, executive functioning measures/immediate memory measures, executive functioning measures/delayed memory measures) yielded two significant canonical variates. According to Duff and colleagues (2005), results suggest executive functioning is strongly related to all types of memory assessed (i.e., verbal, visual, immediate, and delayed memory), with over 50% of variance in measures of executive functioning and memory shared, on average. Duff and colleagues (2005) conclude that there is overlap or covariation between measures of executive functioning and measures of memory; however, they state that additional research is needed to clarify the implications of this statistical covariation. Specifically, Duff and colleagues pose several questions to guide future research: “which of these components [of executive functioning] impact memory performance, and to what degree?” “Can the executive function components be partialled out of memory test performance and used clinically?”, and “do executive function components impact memory performance differentially in different clinical samples?” (p. 121).

Although Duff et al. (2005) suggest examining the relationship between memory and executive functioning in other clinical populations, limited research has examined this

relationship using neurotypical samples. It is important to examine the relationship between neurocognitive constructs in neurotypical populations to reduce the impact of potential confounds. Clinical samples are more likely to include patients with known or suspected memory impairment or executive dysfunction; this may negatively impact researchers' and clinicians' ability to understand the relationship between intact memory and executive functioning. This issue is illustrated by Duff and colleagues' statement that results of their study "might reflect patterns inherent [to] the sample rather than patterns inherent in the measures/constructs" (Duff et al., 2005, p. 119). They further explain, "there may have been two subsets of participants, one doing well and one doing poorly, rather than two independent relationships between the constructs" (p. 119). Given this concern, it is important that the relationship between memory and executive functioning be examined using a sample for which memory and executive functioning are expected to be intact (i.e., a neurotypical sample).

Another consideration with the Duff et al. (2005) study is the use of older measures of memory and executive functioning (i.e., measures published between 1941 and 1989). Since the time these measures were published, revised measures of memory and updated measures of executive functioning have been released. Newer measures often provide updated norming samples which are more consistent with current population demographics. In addition, newer neuropsychological assessments, like the D-KEFS, incorporate the Boston process approach (Kaplan, 1988; Kaplan, 1990; Milberg, Hebben, & Kaplan, 1986), which facilitates the consideration of underlying variables which may impact examinees' strategies for task completion as well as their performance. For example, the D-KEFS includes additional measures of component skills thought to underlie performance on executive functioning tasks;

this allows examiners to consider examinees' strategies and error patterns when interpreting examinees' executive functioning scores. Clinically, the process approach provides neuropsychologists with additional information to inform diagnostic considerations and intervention recommendations and to monitor potential recovery over time (Kaplan, 1990); theoretically, the process approach provides additional data useful in the development and evaluation of theories (Homack, Lee, & Riccio, 2005) as well as data useful for understanding the relationships between neurocognitive constructs.

The present study was designed to examine the relationship between memory and executive functioning in a sample of college students assumed to be neurotypical in terms of development. Although past research has examined the relationship between executive functioning and memory, additional research with neurotypical samples is needed to clarify which aspects of memory and executive functioning are related. In addition, research with newer measures that incorporate the process approach (e.g., the D-KEFS) has the potential to further clarify whether component processes explain the relationship between measures of memory and executive functioning.

As part of a larger study, a sample of college students completed the WMS-IV and the D-KEFS Trail Making Test and Color Word Interference Test. These assessments are two of the most commonly used measures of memory and executive functioning today (Rabin et al., 2016). The WMS-IV is made up of ten subtests which measure a range of auditory memory, visual memory, and visual working memory functions. The D-KEFS Trail Making Test has five conditions (i.e., Visual Scanning, Number Sequencing, Letter Sequencing, Number-Letter Switching, and Motor Speed), and the D-KEFS Color-Word Interference Test has four

conditions (i.e., Color Naming, Word Reading, Inhibition, and Inhibition/Switching). The D-KEFS Trail Making Test Number-Letter Switching condition and the D-KEFS Color-Word Interference Test Inhibition and Inhibition/Switching conditions are modified versions of classic executive functioning tasks (i.e., the Trail Making Test [TMT] from the *Halstead-Reitan Neuropsychological Battery* [Reitan & Wolfson, 1993] and the Stroop test [Stroop, 1935]). The other conditions of the D-KEFS Trail Making and Color-Word Interference tests are used to obtain process scores.

Canonical correlation analyses were used in the study to examine the relationship between WMS-IV subtests and D-KEFS conditions and answer the research questions outlined below. Results of the present study add to current evidence of the construct validity of the WMS-IV and the D-KEFS by verifying whether they have adequate construct validity as measures of memory and executive functioning or whether one of both assessments inadvertently measure constructs they were not intended to measure. Results were used to determine whether measures of set-shifting or inhibition are more strongly associated with measures of memory and whether process scores from the D-KEFS can be used to further explain the relationship between memory and executive functioning.

Research Questions and Hypotheses

Results of the study were used to answer the following research questions. Research question #1 is the primary research question which focuses on the relationship between measures of memory and executive functioning. Research question #2 is designed to examine the impact of additional D-KEFS condition scores on the relationship.

R1. What is the relationship between memory and executive functioning as measured by

- WMS-IV subtests (i.e., Logical Memory I and II, Verbal Paired Associates I and II, Designs I and II, Visual Reproduction I and II, Spatial Addition, and Symbol Span) and D-KEFS scores primarily associated with executive functioning (i.e., the Trail Making Test Number-Letter Switching condition and the Color-Word Interference Test Inhibition and Inhibition/Switching conditions)?
- a. Which subtest scaled scores from the WMS-IV contribute most to the relationship?
 - b. Which scaled scores from the D-KEFS Trail Making and Color-Word Interference tests contribute most to the relationship?
- R2. What is the relationship between participants' performance on WMS-IV subtests (i.e., Logical Memory I and II, Verbal Paired Associates I and II, Designs I and II, Visual Reproduction I and II, Spatial Addition, and Symbol Span), scaled scores on *all* conditions of the D-KEFS Trail Making Test (i.e., Visual Scanning, Number Sequencing, Letter Sequencing, Number-Letter Switching, and Motor Speed), and scaled scores on *all* conditions of the D-KEFS Color-Word Interference Test (i.e., Color Naming, Word Reading, Inhibition, and Inhibition/Switching)?
- a. Which subtest scores from the WMS-IV contribute most to the relationship?
 - b. Which scaled scores from the D-KEFS contribute most to the relationship?

Given past research on memory executive functioning, the following hypotheses were proposed:

- H1. Results of past research suggest a strong relationship between verbal memory and executive functioning, particularly verbal list learning and set shifting (Vanderploeg

et al., 1994; Tremont et al., 2000; Duff et al., 2005). Therefore, it was predicted that participants' performance on verbal memory subtests of the WMS-IV (i.e., Logical Memory I, Logical Memory II, Verbal Paired Associates I, and Verbal Paired Associates II) would be related to their performance on the D-KEFS Color-Word Interference and Trail Making test conditions associated with executive functioning (i.e., the Color-Word Interference Test Inhibition and Inhibition/Switching conditions and the Trail Making Test Number-Letter Switching condition).

- a. Given results of the Vanderploeg et al. (1994) and Tremont et al. (2000) studies, it was expected that participants' performance on the WMS-IV Verbal Paired Associates subtests and their performance on the D-KEFS Trail Making Test Number-Letter Switching condition would be important contributors to the overall relationship.
- H2. Given that verbal functions are generally lateralized to the dominant hemisphere of the brain (Lezak et al., 2012), it was also expected that participants' performance on verbal memory subtests on the WMS-IV (i.e., Logical Memory I, Logical Memory II, Verbal Paired Associates I, and Verbal Paired Associates II) would be related to their performance on *all* of the conditions of the D-KEFS Color-Word Interference Test (i.e., Color Naming, Word Reading, Inhibition, and Inhibition/Switching).
- H3. Past research also suggests a strong relationship exists between visual memory and executive functioning (Duff et al., 2005). Therefore, it was predicted that participants' performance on visual memory subtests of the WMS-IV (i.e., Visual Reproduction I, Visual Reproduction II, Designs I, Designs II) would be related to

- their performance on the D-KEFS Trail Making and Color-Word Interference test conditions associated with executive functioning (i.e., the Trail Making Test Number-Letter Switching condition and the Color-Word Interference Inhibition and Inhibition/Switching conditions).
- H4. Given that visual-spatial tasks are thought to be more lateralized to the nondominant hemisphere of the brain (Lezak et al., 2012), it was also expected that participants' performance on visual memory subtests on the WMS-IV (i.e., Visual Reproduction I, Visual Reproduction II, Designs I, Designs II) would be related to their performance on visually-based tasks on the D-KEFS (i.e., Trail Making Test conditions: Visual Scanning, Number Sequencing, Letter Sequencing, Number-Letter Switching, and Motor Speed).
- H5. Given the theoretical relationship and overlap in neuroanatomical correlates of executive functioning and working memory (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Wager & Smith, 2003), it was expected that participants' performance on visual working memory subtests from the WMS-IV (i.e., Spatial Addition and Symbol Span) would be related to their performance on the D-KEFS Trail Making and Color-Word Interference test conditions associated with executive functioning (i.e., the Trail Making Test Number-Letter Switching condition and the Color-Word Interference Inhibition and Inhibition/Switching conditions).
- a. Given that WMS-IV working memory subtests are visual in nature, it was expected that the D-KEFS Trail Making Test Number-Letter Switching condition would be a more important contributor to the relationship than verbally-based

DIVERGENT VALIDITY OF THE WMS-IV AND D-KEFS 17

executive functioning tasks (i.e., the Color-Word Interference Test Inhibition and Inhibition/Switching conditions).

CHAPTER II

REVIEW OF THE LITERATURE

This review is made of up five major sections: an overview, a review of literature on memory, a review of literature on executive functioning, a review of literature connecting the concepts of memory and executive functioning, a review of the importance of research on memory and executive functioning in neurotypical populations, and a conclusion.

Overview

Measures of intelligence, memory, and executive functioning top the list of assessments most commonly used by neuropsychologists today (Rabin, Paolillo, & Barr, 2016). Although intelligence, memory, and executive functioning are routinely assessed, and deficits in these domains are commonly implicated in a wide variety of conditions, information on the relationships between these constructs is still emerging. Understanding the relationships between neurocognitive abilities is important for researchers as well as practicing neuropsychologists. However, understanding these relationships is particularly important for those who develop and use neuropsychological assessments. Without a comprehensive understanding of what differentiates one neurocognitive ability from another, it is not possible to accurately measure neurocognitive abilities or draw conclusions from patients' patterns of performance on neuropsychological assessments.

For example, recent research has examined the relationship between intelligence and executive functioning to determine how these constructs are related and whether measures of intelligence and executive functioning truly measure unique abilities (Davis et al., 2011; Piehl, 2016; Roberds, 2015). Davis et al. (2011) used canonical correlation analysis to determine the

relationship between intelligence (as measured by the *Wechsler Adult Intelligence Scale, Third Edition* [WAIS-III; Wechsler, 1997a]) and executive function (as measured by the *Delis-Kaplan Executive Function System* [D-KEFS; Delis, Kaplan, & Kramer, 2001a]). Participants were college students, which is an important group to consider as research suggests executive functioning abilities continue to develop throughout childhood and adolescence (Best & Miller, 2010; Golden & Hines, 2011; Olson & Luciana, 2008). Although a large, statistically significant canonical correlation between scores from the WAIS-III and D-KEFS was found, WAIS-III scores had a stronger relationship to the overarching canonical variate than the D-KEFS scores. According to the authors, this suggests the D-KEFS, at least in part, measures constructs which are separate and independent from the construct of intelligence.

In her doctoral dissertation, Roberds (2015) examined this relationship further, using canonical correlation analysis to examine the relationship between intelligence (as measured by the WJ III COG) and executive functioning (as measured by the D-KEFS). WJ III COG and D-KEFS scores both contributed significantly to the canonical correlation, suggesting overlap between the constructs measured by the WJ III COG and the D-KEFS. Roberds (2015) explained that although results suggest some redundancy between the constructs measured, there was also evidence that the WJ III COG and D-KEFS each measure something unique as the variance between the two measures was not all accounted for.

Research is needed to further explain the relationship between intelligence, executive functioning, and other neuropsychological constructs. This study attempts to fill a void in the literature regarding the relationship between executive functioning and memory. In the remainder of this chapter, available information on the history, theory, and neuroanatomical

correlates of memory and executive functions are described. Next, a review of literature on the relationship between these two complex constructs is provided. Finally, a summary of the literature and its relationship to the present study is presented.

Memory

In the early- and mid-1900s when the first comprehensive measures of memory were being developed for clinical use, memory was conceptualized as, “a subset of intelligence,” which in turn was conceptualized as, “a subset of personality and behavior” (Wechsler, 1944 as described by Kent, 2013, p. 278; Wechsler, 1955). Given the relationship between intelligence and memory, David Wechsler, the author of the *Wechsler Memory Scale* (WMS; Wechsler, 1945), designed it to be comparable to his intelligence test, the Wechsler Bellevue Intelligence Scale (WBIS; Wechsler, 1944). The tests were structured similarly to facilitate comparison of scores. Whereas WBIS subtest scores combined to yield an overall intelligence quotient (IQ), seven WMS subtest scores could be combined to yield an overall memory quotient (MQ); Kent, 2013).

In the late 1960s, Atkinson and Shiffrin further advanced understanding of memory when they published their multi-store or modal model of memory. Per the modal model, memory involves three component structures (i.e., the sensory register, the short-term store, and the long-term store), each of which engage in processes which facilitate demonstration of memory (Atkinson & Shiffrin, 1968). That is, to demonstrate that memory has occurred, an individual must first encode information. Individuals passively take in information in the sensory register; Neisser (1967) described this process as a pre-attentive process whereby auditory information enters the echoic memory store, and visual information enters the iconic memory store. This

information is held very briefly and lost if it is not consciously attended to. Although it has a limited capacity, information can be held longer in short-term memory, particularly if conscious rehearsal strategies are employed to keep the information from decaying. From short-term memory, information can be consolidated and stored in long-term memory, which is theoretically unlimited in terms of capacity. Atkinson and Shiffrin (1968) propose that conscious recall of information from long-term memory requires a retrieval process where the information is brought back to the short-term store.

Since Atkinson and Shiffrin's modal model was published, other researchers have attempted to clarify aspects of the model. One key difference between the modal model of memory and more current conceptualizations of memory involves working memory. That is, short-term memory as explained in the modal model is now thought to be encompassed within more contemporary models of working memory, like the multi-component model of working memory (Baddeley, 2000). Measures of memory often differentiate between *immediate memory*, which briefly stores information for immediate retrieval or transfer to long-term memory and *working memory*, which involves manipulation of information held in short-term memory (Baddeley, 2000; Lezak et al., 2012).

Other advances in the conceptualization of memory have involved making distinctions among types of memory to facilitate greater understanding of how individuals remember different types of information. For example, theorists have distinguished between declarative and nondeclarative memory. Declarative, or explicit, memory is defined as memory for facts (i.e., semantic memory) or events/contexts (i.e., episodic memory); whereas nondeclarative, or implicit, memory is procedure- or skill-based (Squire & Zola, 1996; Eichenbaum, 2004; Parkin,

2001; Lezak et al., 2012). According to the WMS-IV technical manual (Wechsler, 2009b), the WMS-IV is meant to measure declarative episodic memory; i.e., “information presented is novel and contextually bound by the testing situation and requires the examinee to learn and retrieve information” (p. 2).

Neuroanatomical correlates of memory. Given that episodic memory is the focus of most measures of memory, neuroanatomical correlates of episodic memory are the focus of this section. Episodic memory involves multiple component processes (e.g., encoding, storage, retrieval); likewise, multiple areas of the brain are involved in episodic memory. Although the primary area associated with episodic and semantic memory is the medial temporal memory system, other areas of the temporal cortex, the frontal and parietal lobes, and the cerebellum play a role in memory functioning (Rajah & McIntosh, 2005; Nyberg, 2008).

Medial temporal cortex/hippocampus. The medial temporal cortex plays a critical role in learning and memory, including consolidation, recall, and recognition (Brown & Aggleton, 2001; Eichenbaum, 2004; Nyberg, 2008; Squire, & Zola, 1996; Squire, 2009). The role of the medial temporal lobes (including the hippocampus) in memory was first demonstrated by Scoville and Milner (1957), who presented memory and intelligence data for ten patients who underwent bilateral medial temporal lobe resection, typically to treat psychosis or intractable seizures. One of the cases described was the case of H.M., one the most famous cases in the field of neuroscience, as it prompted a surge of research into what is now known as the medial temporal memory system (Squire, 2009). Following surgical resection of brain tissue in the medial temporal lobe, H.M. suffered significant anterograde amnesia which Scoville and Milner (1957) describe as, “a grave loss of recent memory” (p. 11) and Lezak et al. (2012) describe as,

“a profound inability to learn new information” (p. 83). Other patients who underwent similar surgical resection also experienced recent memory difficulties of varying severity, depending on how much of the medial temporal lobe hippocampal area was removed (Scoville & Milner, 1957). Of note, results of Scoville and Milner’s study and results of subsequent studies suggest damage to the medial temporal memory system does not impact nondeclarative/procedural memory (Milner, 1962) or remote, non-autobiographical memory (Milner, Corkin, & Teuber, 1968).

Frontal lobes. Although the frontal lobes are more typically associated with attention and executive functioning than memory, individuals with damage to the frontal lobes often exhibit memory impairment (Wheeler, Stuss, & Tulving, 1995; MacPherson, Turner, Bozzali, Cipolatti, & Shallice, 2016). Lezak et al. (2011) describes the role of the prefrontal cortex in memory functioning as a facilitating role. That is, impairment in functions associated with the prefrontal cortex which should theoretically facilitate memory (e.g., learning and retrieval strategies, organization of information to facilitate encoding and retrieval) may mimic memory problems or exacerbate memory difficulties.

In a review of their own research with patients with frontal lobe damage, Stuss and Alexander (2005) examined the relationship between memory impairment and frontal lobe damage. They concluded that while damage in certain areas of the frontal lobes is not associated with memory impairment, damage in other areas of the frontal lobes is associated with impairment in “some aspects of memory (e.g., encoding)” (Stuss & Alexander, 2005, p. 86). For example, results of a study by Stuss, Alexander, Palumbo, Buckle, Sayer, and Pogue (1994) suggests patients with left or bilateral frontal damage had difficulty with free recall and

recognition of items on a verbal list learning task. Further analysis of the results suggested patients with inferior medial frontal damage or left dorsolateral prefrontal cortex damage struggled with recognition of target words following a verbal learning task secondary to encoding or language deficits, respectively). Although patients with right frontal damage did not demonstrate difficulty with free recall or recognition of items, they demonstrated difficulty using organizational strategies to facilitate consistent retrieval of information on the verbal learning task (i.e., from trial to trial, patients with right frontal damage did not consistently recall the same words). Stuss and Alexander (2005) conclude that these results support the idea that observed memory problems in patients with frontal lobe dysfunction may be the results of difficulties with underlying component skills (e.g., encoding, retrieval strategies) necessary for demonstration of memory and learning. That is, in the Stuss et al. (1994) study, patients with left dorsolateral prefrontal cortex damage had difficulty encoding and consolidating verbal information, and patients with inferior medial frontal cortex damage had language difficulties which also negatively impacted efficient encoding. Results of the Stuss et al. (1994) study are supported by results of a positron emission tomography (PET) study by Tulving, Kapur, Craik, Moscovitch, and Houle (1994) which suggest asymmetry in activation of the prefrontal cortex during encoding versus retrieval. PET results suggested the left prefrontal cortex was more activated when participants encoded information into episodic memory or retrieved information from semantic memory while the right prefrontal cortex was more activated when participants retrieved information from episodic memory.

Apart from strategies which facilitate memory, another frontal lobe function relevant to the discussion of neuroanatomical correlates of memory is working memory. Gunning-Dixon &

Raz (2003) studied neuroanatomical correlates of working memory and perseverative behavior in a sample of 139 healthy adults. Based on previous research, Gunning-Dixon and Raz hypothesized that working memory and perseveration would be related to decreased volume in the prefrontal cortex and increased white matter hyperintensities (i.e., small subcortical lesions) in the frontal lobes as measured via magnetic resonance imaging (MRI). Results supported one of the researchers' hypotheses; the volume of the prefrontal cortex and the severity of frontal white matter hyperintensities were related to perseveration. However, results did not suggest a relationship between decreased prefrontal cortex volume/increased frontal white matter hyperintensities and working memory; rather, Gunning-Dixon and Raz (2003) note that subcortical white matter tracts connecting anterior and posterior areas of the brain may play a role in complex working memory tasks like the ones used in their study.

A meta-analysis published in 2003 further clarified the neuroanatomical basis of working memory. Wager and Smith (2003) analyzed 60 fMRI and PET studies and drew conclusions about activation patterns during different types of working memory tasks. Wager and Smith differentiated between verbal working memory, spatial working memory, and object working memory tasks but also between short-term storage (i.e., holding information in memory for a brief period) and executive working memory (i.e., manipulating, ordering, or updating information held in working memory). Results suggested the right parietal cortex was activated for short-term storage of spatial information, the right frontal and bilateral inferior temporal cortices were activated for object information. These results are consistent with how visual information is perceived (i.e., via the dorsal and ventral pathways). Results of Wager and Smith's meta-analysis differed from past research in that modality-related (i.e., verbal vs. spatial

vs. object) differences in activation in the prefrontal cortex during working memory tasks were not supported; however, Wager and Smith proposed that the activation patterns were consistent with how participants may have been holding the information (e.g., subvocally rehearsing verbal information, rehearsing spatial movements, attending to features of the objects). ‘Executive processing’ of information (e.g., manipulating, ordering, updating) was associated with increased activation in the frontal and parietal lobes. Specifically, the right dorsolateral prefrontal cortex, right medial prefrontal cortex, and bilateral superior frontal sulci were activated during ordering and updating, and the superior parietal cortex “trended toward specialization for manipulation” (Wager & Smith, 2003, p. 265). Although multiple areas of the brain are activated when information is initially processed and held in memory, executive processing of information in working memory appears to consistently activate the prefrontal cortex and superior parietal cortex.

Other neuroanatomical correlates. Other areas of the brain which play a role in memory encoding, storage, and retrieval include the lateral temporal cortex, the amygdala, the parietal lobes, and the cerebellum (Nyberg, 2008). Eichenbaum (2004) and Nyberg (2008) propose that connections between the lateral temporal cortex and the medial temporal cortex are associated with episodic memory functioning. Also, through connections to the medial temporal area, the amygdala plays a role in memory by assigning emotional valence to memory which thereby influences encoding, consolidation, and recall of emotionally-charged memories (Dolcos, LaBar, & Cabeza, 2004; LaBar & Cabeza, 2006). The parietal lobes also facilitate episodic memory via their role in attention; however, they may also be involved in recognition (Wagner, Shannon, Kahn, & Buckner, 2005). Functional magnetic resonance imaging (fMRI) research also suggests

the cerebellum may be involved in encoding episodic information (Fleissbach, Trautner, Quesada, Elger, & Weber, 2007).

Measurement of memory. Because memory functioning is subject to change as a result of normal aging as well as acquired conditions (e.g., dementia), valid and reliable measures of memory are needed tools for psychologists and neuropsychologists to assess memory functioning and determine whether or not impairment exists and/or decline has occurred. Given that different degenerative conditions affect different areas of the brain it is important for neuropsychologists to carefully assess each aspect of memory.

Although many measures of memory are available (e.g., *California Verbal Learning Test – Second Edition* [CVLT-II; Delis et al., 2000], *Rey-Osterreith Complex Figure Test* [ROCFT; Rey, 1941], *Wide Range Assessment of Memory and Learning – Second Edition* [WRAML-2; Sheslow & Adams, 2003], *Brief Visuospatial Memory Test – Revised* [BVMT-R; Benedict, 1997], *Rey Auditory Verbal Learning Test* [RAVLT; Rey, 1941; Rey, 1964], etc.), a survey of clinical neuropsychologists published in 2016 (Rabin et al., 2016) suggests the most widely used instrument for the measurement of various types of memory is the *Wechsler Memory Scale – Fourth Edition* (WMS-IV; Wechsler, 2009a). The WMS-IV is the most recent iteration of the WMS. Iterations of the WMS have been the most-used memory tests in the field for over three decades, and each iteration has had strong evidence of reliability and validity (Lubin, Larsen, & Matarazzo, 1984; Rabin et al. 2016). Evidence of reliability and validity for the WMS-IV is discussed in Chapter III.

Despite its popularity, history of revision, and current evidence of reliability and validity, the WMS-IV is not without limitations. In a review of the history of the WMS, Kent (2013)

describes its development and revision history as well as concerns regarding the factor structure of the WMS and its relationship with theory and neuroanatomical conceptualizations of memory. Kent's consistent critique of each iteration of the WMS is that the test is not based on current theories of memory or known neuroanatomical correlates of memory (2013). In addition, Kent (2013) proposes that over time the WMS has become more complicated to score and interpret, "at the expense of clinical usefulness" (p. 289). That is, although the underlying factor structure of the WMS has remained relatively unchanged over time, additional subtests have been added and increasing amounts of data are available which complicate interpretation (Kent, 2013). In addition, the factor structure of the WMS-IV is not mirrored by the available indices; although the test was meant to measure three factors (i.e., auditory memory, visual memory, and visual working memory; Hoelzle et al., 2011), five index scores can be calculated. The immediate and delayed memory indices of the WMS-IV are not supported by the factor structure of the test (Holdnack & Drozdick, 2009; Kent, 2013).

The factor structure of the WMS-IV has also been examined in combination with other measures. For example, Holdnack, Zhou, Larrabee, Millis, & Salthouse (2011) used confirmatory factor analysis to examine the joint factor structure of the WMS-IV and the *Wechsler Adult Intelligence Scale, Fourth Edition* (WAIS-IV; Wechsler, 2008) using data from the WAIS-IV/WMS-IV standardization sample. Results of the study suggest two different factor solutions with very similar fit statistics may be appropriate (i.e., a five-factor solution with a hierarchical general ability factor and a seven-factor solution without a general ability factor). The seven-factor solution includes the following factors: verbal comprehension, perceptual reasoning, auditory working memory, visual working memory, processing speed, auditory

memory, and visual memory; whereas the five-factor solution includes a hierarchical general ability factor and does not separate visual and auditory memory or working memory. Holdnack et al. (2011) state, “the combined factor structure supports some overlap in the constructs measured across the two boundaries (i.e., working memory) but primarily shows the distinctiveness of the constructs measured across the two batteries” (p. 188). This data supports the index models of the WAIS-IV and WMS-IV as all WAIS-IV composites are represented, and all WMS-IV composites except Immediate Memory are represented. It is important to note that subtests which factor into the WMS-IV Immediate Memory composite were not included in the confirmatory factor analysis in this study. Additional research of this nature is important to further validate the factor structure of the WMS-IV, both with the WAIS-IV and with measures of other constructs.

Executive Functioning

Davis, Pierson, and Finch (2011) describe executive functioning as “one of the most widely researched and debated topics in neuropsychology” (p. 61). Agreement on an overarching theory of executive functioning or a widely-accepted definition of executive functioning has not been reached (Salthouse, 2005; Alvarez & Emory, 2006; Jurado & Rosselli, 2007; Davis et al., 2011; Goldstein, Naglieri, Princiotta, & Otero, 2014). In fact, Goldstein et al. (2014) lists over thirty different published definitions of executive functioning.

Davis et al. (2011) explain that the lack of an accepted definition of executive functioning has delayed research regarding the relationship between executive functioning and other domains of neuropsychological functioning (e.g., intelligence, memory, etc.). Although there is still debate regarding an operational definition of executive functioning, Lezak et al. (2012) define

executive functions as the cognitive abilities a person needs to respond adaptively to new or complex situations or problems through intentional, self-directed behavior, planning and decision-making. Latzman and Markon (2010) describe executive function as having the potential to be either risk factors (i.e., if there are deficits in executive functioning) or protective factors (i.e., if an individual shows strength in executive functioning) for behavioral problems. In addition, Lezak and colleagues note that, “although cognitive deficits usually involve specific functions or functional areas; impairments in executive functions tend to show up globally, affecting all aspects of behavior” (p. 37), including adaptive functioning. That is, when executive functions are intact, individuals are typically able to engage in goal-directed behavior and adapt behavior to different situations and experiences. However, when executive functions are impaired, individuals may have great difficulty with goal-directed behaviors because they have difficulty with inhibition/resisting interference (Jefferson, Paul, Ozonoff, & Cohen, 2006). Impairment in executive functioning has a negative impact on a person’s ability to maintain attention, initiate appropriate behaviors, inhibit inappropriate behaviors, and adjust their behavior to shift seamlessly from one task to another.

Executive functioning was initially conceptualized as a unitary cognitive process (i.e., the central executive; Baddeley & Hitch, 1974; Baddeley, 1990). However, more recent research suggests executive functioning may be better conceptualized as several components or processes including but not limited to attention, working memory, planning, inhibition, set shifting or cognitive flexibility, self-regulation or self-monitoring, and verbal fluency (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000; Shimamura, 2000).

Models of executive functioning shed light on key component processes. One model of

executive functioning, proposed by Miyake et al. (2000), has been described as the only available replicated model of executive functioning (Jewsbury et al., 2016). Miyake and colleagues (2000) gave a series of common executive functioning tasks to a group of 137 undergraduate students; they then used confirmatory factor analysis (CFA) to determine whether the data fit an a priori, three-factor model of executive functioning (i.e., shifting, inhibition, and updating). Results suggest the data fit the three-factor model; however, model fit for a three independent factors model was poor. Miyake and colleagues (2000) concluded that shifting, inhibition, and updating are distinct but related constructs; further analysis, using structural equation modeling (SEM) suggest components of executive functioning “contribute differentially to performance on commonly used executive tasks” (Miyake et al., 2000, p. 87).

Other models of executive functioning have focused on the neural basis of executive functioning processes (Shimamura, 2000; Miller & Cohen, 2001). For example, the dynamic filtering theory posits that the prefrontal cortex filters neural functioning via four processes: selective attention, maintenance of information in short-term memory, updating or manipulation of information in short-term memory, and rerouting or set-shifting (Shimamura, 2000).

Research has also examined the relationship between executive functioning and intelligence. Unsworth et al. (2009) examined the relationship between executive functioning, fluid intelligence, and personality. One hundred and thirty-eight college students completed a series of seven executive functioning tasks, two measures of fluid intelligence (i.e., Raven’s Progressive Matrices [Raven, Raven, & Court, 1978] and a number series task), and three personality measures (i.e., the *NEO Personality Inventory Revised* [NEO-PI-R; Costa & McCrae, 1992], the *Behavioral Inhibition/Behavioral Activation Systems* [BIS/BAS; Carver & White,

1994], and the *Personality Disorder Questionnaire* [PDQ-4+; Hyler, 1994]). Results of a confirmatory factor analysis on the executive functioning and fluid intelligence data suggested model fit for a five-factor model (i.e., one fluid intelligence factor and four executive function factors) was acceptable; however, correlations between factors were statistically significant. This is consistent with Miyake and colleagues' (2000) conclusions that executive functions are distinct, but related.

Floyd, Bergeron, Hamilton, and Parra (2010) examined whether executive functions fit within the Cattell-Horn-Carroll (CHC) theory of cognitive abilities (Carroll, 1993; Carroll, 2005; McGrew, 2005; McGrew, 2009; Floyd et al., 2010). Results of a study that examined the relationship between the D-KEFS and the Woodcock-Johnson III Tests of Cognitive Abilities (WJ III; Woodcock, McGrew, & Mather; 2001, 2007) from the lens of CHC theory suggest, “measures of executive functions and measures of CHC cognitive abilities are not easily distinguished” (Floyd et al., 2010); that is, D-KEFS tests load on a general CHC factor as well as CHC broad ability factors. Specifically, exploratory factor analysis (EFA) of D-KEFS and WJ-III tests yielded a six-factor solution. Four factors were identified as measuring CHC broad cognitive abilities: Comprehension-Knowledge (*Gc*), Processing Speed (*Gs*), Long-term Storage and Retrieval (*Gl*), Short-term Memory (*Gsm*), and Visual Processing (*Gv*), and one factor was identified as measuring broad executive functions not accounted for by a CHC broad ability. All factors included tests from both the D-KEFS and the WJ III except the *Gv* factor, which only included WJ III tests. Several confirmatory factor analyses were used to test hypotheses about the relationships between executive functions and cognitive abilities. Overall, results suggest there is overlap between measures of executive functions and CHC cognitive abilities, and Floyd

et al. (2010) recommend diminishing the distinction between these two domains.

Neuroanatomical correlates of executive functioning. One of the first documented cases of executive functioning impairment which fostered initial understanding of the localization of executive functioning in the brain was the case of Phineas Gage. Phineas Gage was a railroad worker who sustained a penetrating head injury during an explosion in the mid-1800s. Damasio, Grabowski, Frank, Galaburda, and Damasio (1994) describe the accident as follows:

In order to lay new rail tracks across Vermont, it was necessary to level the uneven terrain by controlled blasting. Among other tasks, Gage was in charge of the detonations, which involved drilling holes in the stone, partially filling the holes with explosive powder, covering the powder with sand, and using a fuse and a tamping iron to trigger an explosion into the rock. On that fateful day, a momentary distraction let Gage begin tamping directly over the powder before his assistant had had a change to cover it with sand. The result was a powerful explosion away from the rock and toward Gage. The fine-pointed, 109-cm-long tamping iron was hurled, rocket-like, through his face, skull, brain, and then into the sky (p. 1102).

As a result of the blast, a tamping iron entered Gage's left cheek, passed through his left frontal lobe, and exited the top of the skull (Harlow, 1848; Damasio et al., 1994; MacMillan, 2000; Lezak et al., 2012). Following this injury, those who knew Gage noticed dramatic changes in his personality and behavior; specifically, increased irritability and social inappropriateness and difficulties with independent living and maintaining employment (Damasio et al., 1994).

Over time, neuropsychological assessment has been used to further localize executive

functions within the brain; and more recently, neuroimaging studies have shed more light on the neuroanatomical correlates of executive functioning. In 2007, Jurado and Rosselli published a review of literature on executive functioning which summarized neuroimaging research from the 1990s and early 2000s. Jurado and Rosselli concluded that the frontal lobes have a critical role in executive functioning; however, “the integrity of the whole brain is necessary for optimal performance on executive tasks” (p. 217). A recent review of literature on the neuroanatomical correlates of executive functioning aimed to further generalize findings from multiple clinical samples as well as neurotypical samples (Nowrangi, Lyketsos, Rao, & Munro, 2014). Although research has historically identified the prefrontal cortex (i.e., dorsolateral prefrontal cortex, medial prefrontal cortex/anterior cingulate cortex, ventromedial prefrontal cortex/orbitofrontal cortex, inferior frontal cortex) as the region of the brain most associated with executive functions, recent research has identified activation in other cortical and subcortical areas of the brain during executive function tasks (e.g., parietal lobe, cerebellum, basal ganglia; Carpenter, Just & Reichle, 2000; Robinson, Calamia, Gläscher, Bruss, & Tranel, 2014, Tamnes, Østby, Walhovd, Westye, Due-Tønnessenb, and Fjell, 2010). Nowrangi and colleagues’ review supports the idea that executive functioning requires the involvement of a network of brain regions (i.e., other areas of the frontal and parietal lobes and the cerebellum); however, Nowrangi et al. (2014) suggest some executive functions may be more localized while others may require coordination of multiple cortical and subcortical areas of the brain. Results of neuroimaging research for specific executive functions are summarized below.

Working memory. Working memory is defined as a limited-capacity storage and processing center which allows people to hold small amounts of information and manipulate it to

perform mental operations (Lezak et al., 2012). Although working memory is included in theories of memory (e.g., Baddeley, 2000) and measured via cognitive and memory assessments (e.g., Wechsler Intelligence Scales, WMS-IV), it is also sometimes conceptualized as an executive function because it requires attention and inhibition. In fact, based on a factor analytic study on measures of executive functioning and working memory capacity, McCabe, Roediger, McDaniel, Balota, and Hambrick (2010) proposed that executive functioning and working memory measures are highly correlated (i.e., $r = .97$) and share a common core feature, which they call executive attention. Although the neuroanatomical underpinnings of working memory were discussed above in the ‘neuroanatomical correlates of memory section,’ this section includes results of a diffusion tensor imaging (DTI) study which conceptualizes working memory as an executive function and compares white matter tract integrity and performance on measures of working memory and various measures of executive functioning. DTI is used to examine white matter tract connectivity (Jones & Leemans, 2011; Nogle, Horwitz, & Davis, 2011). Grambaite et al. (2014) used DTI to examine potential neuroanatomical underpinnings of executive dysfunction in patients with attention/executive mild cognitive impairment (a/e MCI); specifically, DTI was used to evaluate white matter tract integrity and cortical thickness. Participants completed a battery of neuropsychological tests which included measures of general intellectual ability, memory, language, visuospatial ability, attention, and executive functioning (i.e., working memory, verbal fluency, divided attention, and inhibition/switching). Grambaite and colleagues used the WMS-R Letter-Number Sequencing subtest (Wechsler, 1984) to assess working memory. Results did not suggest a significant relationship between performance on the working memory task and cortical thinning or white matter tract degeneration in the frontal or

cingulate cortices (Grambaite et al., 2014); however, results supported extant literature on the neuroanatomical correlates of other executive functions which are described in subsequent sections.

Verbal fluency. Verbal fluency is defined as an individual's ability to quickly produce speech; two types of verbal fluency commonly assessed in neuropsychological evaluations are phonemic fluency and semantic fluency. Phonemic fluency refers to quickly listing words that start with a given letter, while semantic fluency refers to quickly listing words that fit within a given category (Lezak et al., 2012). Research suggests phonemic fluency is associated with anterior cortical functioning impacted by damage to the frontal lobe, while semantic fluency is associated with damage to the temporal lobe (Baldo, Schwartz, Wilkins, & Dronkers, 2006; Birn et al., 2010).

In the DTI study described above, Grambaite et al. (2014) included a measure of phonemic fluency (i.e., the *Controlled Oral Word Association Test* [COWAT; Benton & Hamsher, 1989]). Similar to results for working memory, DTI results did not suggest a significant relationship between performance on the COWAT and cortical thinning or white matter tract degeneration in the frontal or cingulate cortices in patients with a/e MCI (Grambaite et al., 2014).

Inhibition and set shifting. Neuroanatomical correlates of set-shifting have been examined using neuroimaging technology. The Grambaite et al. (2014) study, described above, extended knowledge regarding the neuroanatomical correlates of divided attention and set shifting in individuals with a/e MCI. Participants completed the Trail Making Test, Part B (TMT-B; Reitan & Wolfson 1993) and the D-KEFS Color-Word Interference Test (Delis et al.,

2001a), which are both iterations of classic measures of cognitive flexibility. While the Trail Making Test requires visual attention and shifting, the D-KEFS Color-Word Interference Test requires both inhibition and shifting. DTI results suggested poor divided visual attention and shifting, as measured by the TMT-B, was associated with cortical thinning in the caudal middle frontal region of the brain; however, differences in levels of cortical thinning for control participants and participants with a/e MCI were not statistically significant (Grambaite et al., 2014). Poor verbal inhibition/switching ability in patients with a/e MCI was associated with white matter tract degeneration in frontal and cingulate cortices of the brain.

Prior to Grambaite and colleagues' study, set shifting abilities had been examined using other neuropsychological and neuroimaging methods. For example, Yochim, Baldo, Nelson, and Delis (2007) studied set shifting in patients with known lateral prefrontal cortex lesions which were evident on computed tomography (CT) or MRI scans. Participants with lateral prefrontal lesions and healthy control participants completed the D-KEFS Trail Making Test. Results suggested participants with lateral prefrontal cortex lesions struggled with the motor speed, letter sequencing, and number letter switching conditions of the D-KEFS Trail Making Test when compared to neurotypical participants. Further, set shifting was significantly impaired even when visual scanning, number sequencing, letter sequencing, and motor speed were controlled (Yochim et al., 2007).

Volumetric differences associated with set shifting have also been examined in prior research. Kramer and colleagues (2007) used MRI to examine potential lobar volume differences (i.e., differences in the volume of the lobes of the brain) associated with set-shifting ability in neurotypical participants and patients with diagnoses of probable Alzheimer's disease,

semantic dementia, or frontotemporal dementia. The D-KEFS Design Fluency Test shifting condition was used to measure set-shifting, and the researchers controlled for performance on the Mini-Mental State Examination (MMSE) and control condition of the Design Fluency tests. Results suggested a relationship between set-shifting ability and bilateral frontal lobe volume for the sample, but particularly for patients with frontotemporal and semantic dementia (Kramer et al., 2007).

Measurement of executive functions. Given the role of the prefrontal cortex in executive functioning and the fact that the prefrontal cortex is not typically fully myelinated until early adulthood, it is not surprising that executive functioning does not develop at a consistent rate. In addition, there are known gender differences in development of executive functions (Anderson, 2002). Executive dysfunction is associated with a number of developmental and acquired conditions such as very preterm birth (Luu, Ment, Allan, Schneider, & Vohr, 2010; Ritter, Perrig, Steinlin, & Everts, 2014), attention-deficit/hyperactivity disorder (Barkley, 1997; Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Pennington & Ozonoff, 1996), autism spectrum disorder (Corbett et al., 2009; Hill, 2004; Kleinhans, Akshoomoff, & Delis, 2005; Pennington & Ozonoff, 1996), and fetal alcohol spectrum disorders (Kodituwakku, 2009; Mattson, Goodman, Caine, Delis, & Riley, 1999; Mattson, Crocker, & Nguyen, 2011). Executive function deficits are also a hallmark symptoms of certain types of dementia including frontotemporal dementia (FTD; Bozeat, Gregory, Ralph, & Hodges, 2000; Ramanan et al., 2017) and vascular dementia. (Looi & Sachdev, 1999; O'Brien et al., 2003), and impairment in certain executive functions is associated with normal aging (Harada, Natelson Love, & Triebel, 2013; Turner & Spreng, 2012; Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000). Given that

executive dysfunction is associated with so many neurodevelopmental and acquired conditions, it is important that neuropsychologists have valid and reliable assessment tools to determine the presence and degree of executive dysfunction.

Historically, measurement of executive functions has been task-based. Classic tasks known to be sensitive to frontal lobe dysfunction (e.g., the Stoop task [Stroop, 1935], the *Wisconsin Card Sorting Test* [Berg, 1948], the *Trail Making Test* [TMT; Reitan, 1955], the COWAT [Benton & Hamsher, 1989], the Tower of London [Shallice, 1982], and the Tower of Hanoi [Simon, 1975]) have been used over time; however, the task-based approach to measurement of executive functioning has been criticized. For example, Miyake and colleagues (2000) argued:

the precise nature of executive processes implicated in the performance of these tasks is underspecified, to say the least. In other words, there is a paucity of rigorous theoretical analysis and independent empirical evidence regarding what these executive tasks really measure (p. 53).

More recently, classic confrontational executive function tasks have been integrated into norm-referenced executive functioning batteries, some of which also include newer measures of executive functioning. Available confrontational executive function batteries include the *Behavioral Assessment of Dysexecutive Syndrome* (BADS; Burgess, Alderman, Evans, Emslie, & Wilson, 1998), the *Cambridge Neuropsychological Test Automated Battery* (CANTAB; Huppert, Bravne, Paykel, & Beardsall, 1995), and the D-KEFS (Delis et al., 2001a). Of these batteries, only the D-KEFS is included in Rabin and colleagues' (2016) list of most frequently used assessments in the field of neuropsychology.

The D-KEFS was standardized on a non-clinical sample of over 1,700 children and adults determined to be representative of the U. S. population based on U. S. Census data from 2000 (Homack, et al., 2005); it is made up of nine independent tests designed to measure a variety of executive functions; although many of the tests are modified versions of tests previously developed for use in clinical or research settings, some tests are new (Delis et al., 2001a). For example, the Trail Making Test, Color-Word Interference Test, and Verbal Fluency Test are modified versions of the *Halstead-Reitan Trail Making Test* (Reitan & Wolfson, 1993), the Stroop test (Stroop, 1935), and the *Controlled Oral Word Association Test* (Benton & Hamsher, 1976), respectively. Clinicians can use a flexible approach to assessment by choosing which tests to administer to answer referral questions for their patients (Baron, 2004).

The D-KEFS incorporates the Boston process approach to neuropsychological assessment (Kaplan, 1988; Kaplan, 1990; Milberg, Hebben, & Kaplan, 1986). The process approach takes task components and examinees' errors and strategies into consideration when interpreting results of neuropsychological assessments. Homack and colleagues (2005), consider this a strength of the D-KEFS; several process scores are available for many D-KEFS tests. These additional scores provide useful information about the fundamental component skills related to the higher-order tasks of interest as well as examinees' error patterns and strategies. Although the D-KEFS is described as atheoretical because theories of executive functioning were still under development at the time the D-KEFS was published, the process-oriented measurement of several operationally-defined executive function constructs make D-KEFS data useful in the development and evaluation of theories of executive functioning (Homack et al., 2005).

Despite the popularity of the D-KEFS among neuropsychologists (Rabin et al., 2016), additional research is needed to establish the validity of the D-KEFS as a measure of executive functioning. Reviewers of the D-KEFS express concerns related to small sample size in current validity studies and minimal evidence of concurrent validity (Shunk, Davis, & Dean, 2006). Since this review, additional evidence of validity has been published (Latzman & Markon, 2010; Latzman, Elkovitch, Young, & Clark, 2010); however, there are continued concerns regarding the utility of the D-KEFS for differential diagnosis (Keifer and Tranel, 2013).

The factor structure of the D-KEFS as reported by Latzman and Markon (2010) is consistent with Miyake and colleagues' (2000) switching, inhibition, and updating model of executive functioning. Latzman and Markon (2010) examined the factor structure of the D-KEFS using EFA. EFA was performed on D-KEFS data from both the standardization sample and a community-based sample of males between the ages of 11 and 16. According to the authors, the best-fitting model for the D-KEFS for three age bands (i.e., 8-19, 20-49, and 50-89) was made up of three factors, which were named Conceptual Flexibility, Monitoring, and Inhibition. Scores from the D-KEFS Sorting Test loaded on the Conceptual Flexibility factor, category switching scores from the D-KEFS Verbal Fluency subtest loaded on the Monitoring factor, and scores from the D-KEFS Color-Word Interference Test and Trail Making Test loaded on the Inhibition factor. Latzman and Markon (2010) noted that test scores that loaded less strongly on a single factor also appeared to be more likely to change depending on age band. Results of EFA for the community-based sample also suggested a three-factor solution was the best fit; this solution replicated the three-factor solution found to be the best fit for the data from the standardization sample.

A more recent study by Latzman et al. (2010) extends research on the factor structure of the D-KEFS by connecting it to another construct: academic achievement. In this study, adolescent males completed the *Kaufman Brief Intelligence Test, Second Edition* (KBIT-2; Kaufman & Kaufman, 2006), the D-KEFS, and the *Iowa Tests of Basic Skills* (ITBS, Hoover et al., 2001) or the *Iowa Tests of Educational Development* (ITED; Forsyth et al., 2001), which are standardized tests of academic achievement in reading, mathematics, social studies, and science for grades K through eight and nine through twelve, respectively. Results suggest EF domains (i.e., conceptual flexibility, monitoring, and inhibition) have predictive value for academic achievement in all domains assessed over and above the impact of general intelligence. Specifically, conceptual flexibility was shown to predict reading and science achievement, monitoring was shown to predict social studies and reading achievement, and inhibition was shown to predict math and science achievement.

Despite evidence that the D-KEFS has predictive value for other constructs and the factor structure of the D-KEFS fits with an accepted model of executive functioning, the utility of the D-KEFS for differential diagnosis of frontal lobe dysfunction is questioned. Specifically, Keifer and Tranel (2013) question the sensitivity and specificity of the D-KEFS for differentiating between patients with cortical lesions. To further examine this issue, Keifer and Tranel (2013) analyzed neuropsychological testing data from 45 patients with focal lesions. The authors provided the following information about participants' lesions: "thirteen participants had lesions in the vmPFC [ventromedial prefrontal cortex] ..., and 14 had lesions in the dlPFC [dorsolateral prefrontal cortex] ...several lesions in the dlPFC extended into the superior temporal/parietal regions" (Keifer & Tranel, 2013, p. 1050). Eighteen participants had lesions outside the frontal

lobe. Data from the D-KEFS, the WAIS-III (Wechsler, 1997a) or WAIS-IV (Wechsler, 2008), and the WRAT-3 (Wilkinson, 1993) or WRAT-4 (Wilkinson & Robertson, 2006) were analyzed and compared based on lesion group. Although results suggested statistically significant differences in D-KEFS performance between lesion groups, these differences were not statistically significant after general intellectual functioning was controlled. Keifer and Tranel (2013) question whether the D-KEFS has “an adequate range of items of medium difficulty that would increase the discrimination of its measures” (p. 1056) and conclude that additional research comparing the D-KEFS to previously-validated measures of executive functioning is needed to further establish the sensitivity and specificity of the test battery.

Another validity-related concern raised by both Keifer and Tranel (2013) and a previous study by Lippa and Davis (2010) is that the D-KEFS Color-Word Interference Test conditions may not work as they were intended. That is, in both studies, participants tended to perform better on the inhibition/switching condition than the inhibition condition, which is intended to be simpler. Given these validity concerns, additional research on the D-KEFS and its relationship with other measures is needed.

The Relationship between Memory and Executive Functions

Although the relationship between memory and executive functioning has been previously examined, research on the relationship between the WMS-IV and the D-KEFS is more limited. Prior research suggests there is shared variance between measures of memory and executive functioning. For example, results of a canonical correlation study by Vanderploeg et al. (1994) suggest measures of intelligence (i.e., the WAIS-R), language (i.e., the *Multilingual Aphasia Examination* [Benton & Hamsher, 1983], memory (i.e., the CVLT), and executive

functioning (i.e., the TMT Part B (TMT-B) and the WCST) share variance. Measures of verbal learning, working memory, and set shifting contributed most to the canonical correlation.

Results of another study suggest there is significant overlap or redundancy between measures of memory and executive functioning. Duff, Schoenberg, Scott, & Adams (2005) used canonical correlation analysis to examine shared variance in a battery of neuropsychological tests which included the *Wechsler Adult Intelligence Scale – Revised* (WAIS-R) Similarities subtest, the *Wechsler Memory Scale – Revised* (WMS-R; Wechsler, 1984), the *Rey-Osterreith Complex Figure Test* delayed recall condition (ROCFT; Rey, 1941), WCST (Heaton, 1981), the *Halstead Reitan Trail Making Test Part B* (TMT-B; Reitan & Wolfson, 1993), the COWAT (Benton & Hamsher, 1989), and the *Rey Auditory Verbal Learning Test* (RAVLT; Rey, 1941; Rey, 1964). Results suggested over half the variance was shared, and Duff et al. (2005) concluded the relationship between visual memory and executive functioning explained 59% of the shared variance, and the relationship between verbal memory and executive functioning explained 55% of the shared variance.

Additional research is needed to examine the shared variance between measures of memory and executive functioning currently used in the field of neuropsychology. The WMS-IV and the D-KEFS should theoretically measure related but distinct constructs. If the degree of shared variance between these measures high, the measures lack adequate divergent validity.

A study presented in the WMS-IV Technical Manual (Holdnack & Drozdick, 2009) examines the relationship between the WMS-IV and two D-KEFS tests: the Trail Making Test and the Verbal Fluency test. Holdnack and Drozdick (2009) hypothesized WMS-IV visual working memory subtests (e.g. Spatial Addition and Symbol Span) would be more highly

correlated with D-KEFS performance and WMS-IV auditory memory subtests (e.g., Logical Memory and Verbal Paired Associates) would be more highly correlated with D-KEFS Verbal Fluency performance. Results of the study suggest correlations between subtests from the WMS-IV and two tests from the D-KEFS ranged from weak ($r=.22$) to moderate ($r=.54$). This suggests a relationship, albeit a weak to moderate one, exists between constructs measured by the WMS-IV and the D-KEFS Trail Making and Verbal Fluency Tests.

The present study used canonical correlation analysis to examine the relationship between the WMS-IV, the D-KEFS Trail Making Test, and the D-KEFS Color-Word Interference Test and determine whether these tests measure independent constructs. If significant canonical correlations were found, it would be important to determine which aspects of memory and executing functioning contribute most to the shared variance.

Importance of Research with Neurotypical Populations

Although much of the research on memory and executive functioning involves clinical populations, it is also critical to conduct research with neurotypical samples. Heyanka, Holster, and Golden (2013) state that, “knowledge of patterns of neuropsychological performance among normal, healthy individuals is integral to the practice of clinical neuropsychology” (p. 526). Examining the relationships between neurocognitive constructs in neurotypical populations reduces the impact of potential confounds often present in clinical samples. Researchers’ conclusions about the relationships between constructs may be skewed if participants demonstrate impairment on measures of the constructs being compared. Using data from participants assumed to be neurotypical in terms of development allows researchers to provide a point of comparison for future clinical studies. If the relationship between neurocognitive

constructs is not understood in neurotypical populations, it is then difficult to determine the degree of aberration when overlap or variation is found among these constructs in patients with neurological compromise.

Conclusion

Further research is needed to clarify the relationship between memory and executive functioning. Previous research suggests memory and executive functioning are related constructs, and measures of memory and executive functioning have been shown to have some degree of shared variance. However, establishing evidence of construct validity is an ongoing process, and additional research is needed to determine the degree of shared variance between contemporary measures of memory and executive functioning (i.e., the WMS-IV and the D-KEFS). Results of the present study will supplement available evidence of construct validity for the WMS-IV and the D-KEFS. Low shared variance would support divergent validity of the WMS-IV and the D-KEFS while high shared variance would suggest the tests do not truly measure distinct constructs.

CHAPTER III

METHOD

This chapter includes information on participants, procedures, measures, and statistical analyses. Specifically, the purpose of this chapter is to outline and describe procedures for participant recruitment, selection, compensation, the neuropsychological measures used, the study procedure, and the data analysis plan. Data used in this study was part of data collected in a larger study which examined intelligence, memory, executive function, and suboptimal effort in undergraduate students for which Dr. Andrew Davis was the primary investigator. Data were collected for several consecutive semesters over the course of two years, beginning in April 2014 and ending in April 2016. The university Internal Review Board (IRB) approved the original study in September 2014. Kelly Hoover submitted a proposal to the IRB to analyze the data for her dissertation following approval of this proposal by her committee. The IRB approved the study proposal on April 4, 2017.

Participants

Participants were undergraduate students recruited through an online research participant pool at a Midwestern university. At the time of participation in the larger study, all participants were currently enrolled in introductory psychology or marketing courses. Participants were credited with four hours of research participation which could be used to meet research requirements in their courses.

Exclusion criteria. Participants were excluded from the larger study if they were not students currently enrolled in an introductory psychology or marketing course at the university. Students were also excluded from participation if they were under eighteen years of age, as

individuals under eighteen years old are not legally able to consent to participate in research.

Procedures

Participants were recruited through undergraduate introductory psychology and marketing courses. When they enrolled in these courses, they were given access to an online research participant pool from which they were required to complete four and a half hours of research participation. Participants who signed up for this study were eligible to receive four hours of research participation credit if they met inclusion/exclusion criteria (which was listed on the research participant pool website), came to the study location at the designated time, and gave consent to participate in the study. Examiners informed all participants that they could discontinue their participation in the study at any time for any reason without any negative repercussions (i.e., participants were still given research participation credit if they opted to discontinue the study early).

Given the individual nature of the measures chosen for this study, all participants met with an examiner one-on-one to participate in the study. Doctoral student examiners with training in psychological assessment and in the measures used in the study administered the measures to each participant. Measures were administered in a consistent order for all participants and in accordance with standardization procedures specified in the test manuals.

When a participant arrived, the examiner provided him or her with a copy of an informed consent document, verbally reviewed the contents of the document with the participant (including all inclusion/exclusion criteria, study procedures, data storage and confidentiality), and answered the participant's questions about the consent form. The researcher also informed participants that no feedback of any kind would be given regarding the results of the

assessments; therefore, debriefing was not necessary.

After providing consent, participants responded verbally to a series of demographic and background questions. Then, after completing several measures which are part of the larger study, participants completed the *Wechsler Memory Scale, Fourth Edition* (WMS-IV; Wechsler, 2009a) immediate, working, and delayed memory subtests, the *Delis-Kaplan Executive Function System* (D-KEFS; Delis et al., 2001a) Trail Making Test, and the D-KEFS Color-Word Interference Test.

Measures

Demographic survey. Participants responded verbally to questions regarding their gender, age, race/ethnicity, handedness, education level, SAT/ACT score, and parental education and occupation. Each participant also indicated whether they had a history of Attention-Deficit/Hyperactivity Disorder (ADHD), a learning disorder or learning disability, a traumatic brain injury (TBI), or other medical or psychiatric conditions; participants also provided a list of prescribed and over-the-counter medications they were currently taking. Information collected was used to provide evidence for the representativeness of the sample.

Wechsler Memory Scale, Fourth Edition. The WMS-IV the fourth iteration of the Wechsler Memory Scales (WMS; Wechsler, 1945), which Lezak and colleagues (2012) call, “the most widely used and most recognizable memory battery” in existence (p. 522). The WMS-IV was normed on a sample of 1,400 participants ranging in age from 16 to 90 years old who were representative of U. S. Census data from 2005. The Adult Battery, which was normed on a sample of 900 adults ages 16-69, was used for this study. The WMS-IV Adult Battery is made up of ten subtests (i.e., Logical Memory I and II, Verbal Paired Associates I and II, Designs I and

II, Visual Reproduction I and II, Spatial Addition, and Symbol Span) which yield five overall index scores: Auditory Memory, Visual Memory, Visual Working Memory, Immediate Memory, and Delayed Memory.

Considerable evidence of the reliability of the WMS-IV is available in the test manual (Wechsler, 2009b). Internal consistency reliability coefficients, standard errors of measurement, test-retest reliability coefficients, and inter-scorer agreement values are reported. Average internal consistency reliability coefficients were calculated for each subtest and composite using Fisher's z transformation (Silver & Dunlap, 1987). Overall, internal consistency reliability coefficients fell in the moderate to high range; that is, internal consistency reliability coefficients ranged from .74 to .97 for subtests on the Adult battery and .74 to .96 for subtests on the Older Adult battery (Wechsler, 2009b). Internal consistency reliability estimates for WMS-IV composite scores all fell in the high range.

Test-retest reliability evidence was characterized by greater variability. Wechsler (2009b) notes this is to be expected because, "memory subtests tend to produce lower reliability on test-retest due to the heavy influence of practice effects on memory tasks" (p. 50). Subtest test-retest coefficients corrected for variability in the normative sample ranged from .59 to .77 on the Adult battery and .69 to .81 on the Older Adult battery (Wechsler, 2009b). Inter-scorer agreement was calculated to be 96% to 97% for drawing tasks (Wechsler, 2009b).

Validity evidence presented in the WMS-IV Technical Manual (Holdnack & Drozdick, 2009) includes evidence of content validity, construct validity, and concurrent validity. Holdnack & Drozdick (2009) report that content validity was examined via literature reviews as well as expert reviews of the WMS-IV. Construct validity was examined via intercorrelations of

subtest scores, factor analyses, and evidence of concurrent validity was examined via special group studies and studies of the relationships between the WMS-IV and measures of memory, executive functioning, intellectual functioning, adaptive behavior, and psychiatric symptoms. Overall, based on evaluation of the literature, research on previous versions of the WMS, comparisons of the WMS-IV to other clinical measures, and research with special populations including older adults, patients with probable dementia, patients with mild cognitive impairment, patients with traumatic brain injury, temporal lobe epilepsy, major depressive disorder, schizophrenia, anxiety disorders, intellectual disability, autistic disorder, Asperger's disorder, reading or mathematics disorders, and attention-deficit/hyperactivity disorder, Wechsler (2009b) conclude that initial validity evidence for the WMS-IV is promising.

Delis-Kaplan Executive Function System. The D-KEFS is made up of nine tests of executive functioning normed on a sample of adults and children ages eight to 89 years old who were representative of U. S. Census data from 2000 (Baron, 2004; Homack et al., 2005). Many of the verbal and nonverbal executive functioning tasks that make up the D-KEFS are based upon well-validated, traditionally-used clinical and experimental measures of executive functioning (Homack et al., 2005; Kelly, 2003; Shunk, Davis, & Dean, 2006).

Two D-KEFS tests were administered in the larger study: the Trail Making Test and the Color-Word Interference Test. These tests were chosen for the study due to their long history of use in the field of neuropsychology. Although many D-KEFS tests are based on well-validated measures of executive functioning, the D-KEFS has been critiqued for its evidence of reliability and validity. For example, Schmidt (2003) pointed out that less than 20% of reliability coefficients included in the D-KEFS Technical Manual (Delis, Kaplan, & Kramer, 2001b) meet

generally accepted standards for reliability (i.e., $>.80$). Descriptions of the Trail Making Test and Color-Word Interference Test as well as information on test psychometrics is included below.

The Trail Making Test was designed as a visual-motor measure of executive functioning (i.e., cognitive flexibility); however, it also measures several component skills (i.e., visual scanning, number sequencing, letter sequencing, and motor speed). The D-KEFS Trail Making test is a modification of previously used neuropsychological measures (i.e., the *Partington's Pathways Test* [Partington & Leiter, 1949] and the *Halstead Reitan Neuropsychological Test Battery Trail Making Test* [Reitan & Wolfson, 1993]). Reviews of the D-KEFS by Baron (2004) and Shunk, Davis, and Dean (2006) refer to the D-KEFS Trail Making Test as an improved version of the original trail making tests due to several factors. Some key advantages of the D-KEFS Trail Making Test are its inclusion of a simple search task, separate number and letter sequencing tasks, and a motor speed task. Previous versions (e.g., the Halstead Reitan Trail Making Test) included only two conditions: a number sequencing task and a letter/number switching task. By including additional conditions, the D-KEFS Trail Making Test allows clinicians to parse apart the potential influence of several variables (i.e., visual scanning difficulties, specific sequencing difficulties, motor speed deficits) on examinees' executive functioning. Without these additional conditions, clinicians may inaccurately attribute poor performance on the switching task to an executive function deficit when the true problem may actually involve another underlying deficit.

Available reliability evidence for the D-KEFS Trail Making Test includes internal consistency values for the composite sequencing scores (which includes condition 2: Number Sequencing and condition 3: Letter Sequencing), test-retest data for all five conditions and the

sequencing composite, and standard errors of measurement for the sequencing composite (Delis et al., 2001b). According to Martella, Nelson, Morgan, and Marchand-Martella (2013), reliability coefficients of at least .70 are typically considered acceptable; however, higher coefficients are not uncommon for many standardized assessments. Internal consistency values and standard error of measurement values for the D-KEFS Trail Making Test sequencing composite were largely within acceptable ranges; however, internal consistency values fell below .70 for over a third of the age bands presented (Delis et al., 2001b). Test-retest reliability values for the Trail Making Test ranged from .38 for condition 4 (Switching) to .77 for condition 5 (Motor Speed); overall, test-retest reliability coefficients fell in the moderate range (Delis et al., 2001b).

The Color-Word Interference Test is an iteration of the well-known Stroop test (Stroop, 1935), which was designed to measure participants' ability to inhibit overlearned verbal responses in favor of a 'conflicting response'. According to Baron (2004), the D-KEFS Color-Word Interference Test is similar to an alternate version of the Stroop Color Word Test (Stroop, 1935; Golden, 1978) which requires examinees to complete three tasks. The D-KEFS Color-Word Interference Test adds a fourth task, giving it four conditions total: Color Naming, Word Reading, Inhibition, and Inhibition/Switching (Delis et al., 2001a). Thus, in addition to inhibition, it includes another measure of EF: task switching. The inclusion of these four conditions allows clinicians to draw more accurate conclusions because they have evidence of examinees' ability to perform component skills related to the executive function area of interest. For instance, because measures of color naming and color word reading are included, clinicians will not attribute poor performance on the inhibition and switching tasks to a true executive

function deficit if the examinee demonstrates difficulty naming colors or reading color words.

Available reliability evidence for the Color-Word Interference Test includes split-half internal consistency for the Combined Color Naming + Word Reading composite score, test-retest data for each of the four conditions by age group, and standard error of measurement for the Combined Color Naming + Word Reading composite (Delis, Kaplan, and Kramer; 2001b). Internal consistency values and standard error of measurement values for the combined Color Naming and Word Reading composite fell within acceptable ranges overall; internal consistency values fell slightly below .70 for two age bands (Delis et al., 2001b). Test-retest reliability coefficients ranged from .62 for condition 2 (Word Reading) to .76 for condition 1 (Color Naming; Delis et al., 2001b). Overall, test-retest reliability coefficients fell in the moderate to high range.

Statistical Procedures

Descriptive statistics were used to characterize the demographic characteristics of the sample as well as to illustrate how members of the sample perform in comparison to the norming samples of the WMS-IV and D-KEFS. Next, canonical correlation analysis were used to determine the relationship between memory scores and executive functioning scores. Per Tabachnick and Fidell (2013), canonical correlation analysis is a type of multivariate analysis used to determine how two sets of variables are related to one another. According to Davis et al. (2011), canonical correlation analysis works by, “finding linear combinations within the variable sets that maximize the correlation among them” (p. 64). This allows researchers to determine whether two sets of variables are independent from one another; if a significant canonical correlation is present, the two sets of variables are related to one another. This analysis also

determines which variables within the sets contribute most to the canonical correlation (Davis et al., 2011). Canonical correlation analysis has been described as an exploratory counterpart to structural equation modeling (SEM; Tabachnick and Fidell, 2013). Both canonical correlation analysis and SEM examine the relationships between sets of variables; however, SEM requires the researcher to have strong a priori hypotheses regarding how the variable sets are related, whereas canonical correlation analysis assumes that the underlying dimensions present when variable sets are combined are not known (Tabachnick & Fidell, 2013).

Theoretically, memory and executive functioning are related but separate constructs with largely different neuroanatomical pathways. Although much is known about the relationship between WMS-IV subtests and the relationship between D-KEFS test conditions, previous research has not specifically examined the relationship between the WMS-IV and the D-KEFS Trail Making and Color-Word Interference tests. In addition, past research on other measures of memory and executive functioning has shown mixed results regarding which aspects of executive functioning and memory are related (Vanderploeg, Schinka, & Retzlaff, 1994; Tremont et al., 2000; Duff, Schoenberg, Scott, & Adams, 2005). Therefore, an exploratory analysis with research-driven hypotheses is most appropriate to examine this relationship.

Canonical correlation analyses were used to answer the research questions proposed in Chapter I and determine the relationships between WMS-IV subtests and D-KEFS conditions. Understanding the dimensions that underlie sets of scores from the WMS-IV subtests and the D-KEFS tests helps to clarify whether there is construct overlap between commonly used measures of memory and executive functioning. First, the relationship between the 10 WMS-IV subtests and D-KEFS Trail Making and Color-Word Interference Test condition scores associated with

aspects of executive functioning was examined (see Table 1).

Table 1

WMS-IV Subtests and D-KEFS Conditions included in Canonical Correlation Analysis #1

<u>WMS-IV</u>	<u>D-KEFS Trail Making Test</u>
Logical Memory I	Number-Letter Switching
Logical Memory II	
Verbal Paired Associates I	<u>D-KEFS Color-Word Interference Test</u>
Verbal Paired Associates II	Inhibition
Designs I	Inhibition/Switching
Designs II	
Visual Reproduction I	
Visual Reproduction II	
Spatial Addition	
Symbol Span	

Next, the relationship between the 10 WMS-IV subtests and all conditions of the D-KEFS Trail Making and Color-Word Interference Tests was examined (see Table 2). If hypothesized relationships between measures of verbal and visual executive functioning and measures of verbal memory, visual memory, and visual working memory (described in Chapter I) would not have been evident in the second canonical correlation analysis, additional statistical analyses would have been used to further examine the expected relationships.

Table 2

WMS-IV Subtests and D-KEFS Conditions included in Canonical Correlation #2

<u>WMS-IV</u>	<u>D-KEFS Trail Making Test</u>
Logical Memory I	Visual Scanning
Logical Memory II	Number Sequencing

Verbal Paired Associates I	Letter Sequencing
Verbal Paired Associates II	Number-Letter Switching
Designs I	Motor Speed
Designs II	<u>D-KEFS Color-Word Interference Test</u>
Visual Reproduction I	Color Naming
Visual Reproduction II	Word Reading
Spatial Addition	Inhibition
Symbol Span	Inhibition/Switching

Statistical assumptions for canonical correlation analysis include multivariate normality, linearity, homoscedasticity, and the absence of singularity and multicollinearity. Therefore, prior to running the analyses, it was important to determine whether WMS-IV and D-KEFS scores for all subtests and conditions included in the analyses were normally distributed to increase the probability of multivariate normality (Tabachnick & Fidell, 2013). It was also important to determine whether outliers and/or missing data had an impact on the canonical correlation analysis.

Description of the Sample

Study participants were 51 undergraduate students (28 females, 23 males) at a large, Midwestern university. Descriptive statistics can be found in Table 3. Participants ranged in age from 18 years, 4 months to 26 years, 4 months (M age = 20.21, SD = 1.75). Reported race/ethnicity for the sample was: Caucasian (76.5%), Mixed/Biracial/Multiracial (9.8%), Black/African American (5.9%), Hispanic/Latino (5.9%), and Asian/Asian American (2.0%). The majority of the participants (82.4%) reported they were right-handed, and 17.6% percent reported they were left-handed.

Table 3

Descriptive Statistics for the Sample

<u>Variable</u>	<i>N</i>	(%)
<i>Gender</i>		
Male	23	45.1
Female	28	54.9
<i>Race/Ethnicity</i>		
Caucasian	39	76.5
Mixed/Biracial/Multiracial	5	9.8
Black/African American	3	5.9
Hispanic/Latino	3	5.9
Asian/Asian American	1	2.0
<i>N=51</i>		

Participants self-reported medical and mental health diagnoses (see Table 4). Four participants reported a history of Attention-Deficit/Hyperactivity Disorder (ADHD), two participants reported a history of learning disabilities (LD), and two participants reported a history of traumatic brain injury (TBI). In addition, participants self-reported other medical and mental health conditions with which they had been diagnosed. Nine participants indicated they had been diagnosed with depression (i.e., either unspecified depression or Major Depressive Disorder), five participants indicated they had been diagnosed with anxiety (i.e., unspecified anxiety, Generalized Anxiety Disorder, or Posttraumatic Stress Disorder), two participants indicated they had been diagnosed with seizures, and two participants indicated they had been diagnosed with allergies. Other prior diagnoses self-reported by participants in the sample include anemia, asthma, concussions, insomnia, migraines, Raynaud's, and ulcerative colitis.

Table 4

Medical/mental health diagnoses of participants at the time of participation in the study

Diagnosis	Total Participants
depression (unspecified)	8
ADHD	4
anxiety (unspecified)	3
allergies	2
learning disability	2
seizures	2
TBI	2
anemia	1
asthma	1
concussions	1
Generalized Anxiety Disorder	1
insomnia	1
Major Depressive Disorder	1
migraines	1
Posttraumatic Stress Disorder	1
Raynaud's	1
ulcerative colitis	1

Participants also self-reported prescribed medication, over-the-counter medications, and supplements they were taking at the time of participation in the study (see Table 5). Just under half (47%) of the participants were unmedicated or did not report taking any medications or supplements; 53% of the participants reported taking medications or supplements at the time of participation. The most common medications reported by participants included: Sprintec (8%), Zyrtec (6%), Abilify (4%), Effexor (4%), and Lexapro (4%). Other medications reported included: Beyaz, birth control (unspecified), cephalexin, citalopram, Concerta, dicyclomine, Dulera (inhaler), Elavil, erythromycin, iron, Lialda, lorazepam, Mirena, minocycline, a

multivitamin, Nasonex, nitrofurantoin, Remeron, Seroquel, sertraline, Strattera, Synthroid, Topamax, TriNessa, Tri-Sprintec, Tylenol, vitamin B, Vyvanse, and Zantac. Ten participants (19.6%) reported taking multiple medications/supplements.

Table 5

Medications/supplements reported by participants at the time of participation in the study

Medication/Supplement	Total Participants Prescribed
Sprintec	4
Zyrtec	3
Abilify	2
Effexor	2
Lexapro	2
Beyaz	1
birth control (unspecified)	1
cephalexin	1
citalopram	1
Concerta	1
dicyclomine	1
Dulera	1
Elavil	1
erythromycin	1
iron	1
Lialda	1
lorazepam	1
Mirena	1
minocycline	1
multivitamin	1
Nasonex	1
nitrofurantoin	1
Remeron	1

DIVERGENT VALIDITY OF THE WMS-IV AND D-KEFS 61

Seroquel	1
sertraline	1
Strattera	1
Synthroid	1
Topamax	1
TriNessa	1
Tri-Sprintec	1
Tylenol	1
vitamin B	1
Vyvanse	1
Zantac	1

CHAPTER IV

RESULTS

This chapter provides information about the relationship between participants' performance on measures of memory and executive functioning. Specifically, descriptive statistics and results of canonical correlation analyses are presented. Chapter IV has two major sections: (1) results and analyses and (2) summary.

Results and Analyses

Descriptive Statistics

Descriptive statistics including means and standard deviations of all *Wechsler Memory Scale, Fourth Edition* (WMS-IV; Wechsler, 2009a) composite and subtest scores and *Delis-Kaplan Executive Function System* (D-KEFS; Delis, Kaplan, & Kramer, 2001a) test scores appear in Table 6. Normative data for the WMS-IV, which is based on a representative sample of the United States population based on Census data from 2005, specify a mean score of 10 and a standard deviation of 3 for all WMS-IV subtests. Mean WMS-IV subtest scores for the study sample ranged from 10.24 (Visual Reproduction I) to 11.43 (Verbal Paired Associates II). All mean subtest scores fell within the Average range for the WMS-IV. Similarly, all D-KEFS test scores for the college student sample used in this study fell within expected ranges. Normative data for the D-KEFS indicates all D-KEFS tests have a mean of 10 and a standard deviation of 3. Mean D-KEFS Trail Making Test scores for the study sample ranged from 10.57 (Number-Letter Switching) to 11.47 (Motor Speed); Mean D-KEFS Color-Word Interference Test scores for the sample ranged from 10.63 (Color Naming) to 11.22 (Inhibition).

Table 6

Means and Standard Deviations for the WMS-IV and D-KEFS

Variable	Mean	SD	Minimum	Maximum
WMS-IV Subtests				
Logical Memory I	11.37	2.55	3	18
Logical Memory II	10.92	2.35	5	18
Verbal Paired Associates I	11.14	2.22	3	18
Verbal Paired Associates II	11.43	1.76	4	13
Designs I	11.10	2.74	5	19
Designs II	11.10	2.74	6	17
Visual Reproduction I	10.24	2.73	4	14
Visual Reproduction II	10.65	2.83	6	17
Spatial Addition	10.76	2.82	1	17
Symbol Span	11.31	2.17	7	16
D-KEFS Tests and Conditions				
<u><i>D-KEFS Trail Making Test</i></u>				
Visual Scanning	11.35	1.80	3	15
Number Sequencing	10.82	2.27	1	14
Letter Sequencing	11.16	2.15	4	14
Number-Letter Switching	10.57	1.81	3	13
Motor Speed	11.47	1.14	8	13
<u><i>D-KEFS Color-Word Interference Test</i></u>				
Color Naming	10.63	1.88	5	14
Word Reading	11.20	1.90	4	14
Inhibition	11.22	2.50	3	14
Inhibition/Switching	10.82	2.00	5	14

Pearson product moment correlations between WMS-IV subtests (i.e., Logical Memory I, Logical Memory II, Verbal Paired Associates I, Verbal Paired Associates II, Designs I, Designs

II, Visual Reproduction I, Visual Reproduction II, Spatial Addition, and Symbol Span) and D-KEFS test condition scores from the Trail Making Test (i.e., Visual Scanning, Number Sequencing, Letter Sequencing, Number-Letter Switching, and Motor Speed) and the Color-Word Interference Test (i.e., Color Naming, Word Reading, Inhibition, and Inhibition-Switching) were initially used to assess the relationship between each of the variables. These correlations appear in Table 7.

For the purposes of this analysis, Pearson's r was used as a measure of effect size and interpreted using Cohen's guidelines (Cohen, 1992; Field, 2013). All D-KEFS Trail Making Test conditions were significantly correlated with one or more of the WMS-IV subtests. Medium effect sizes were indicated for the significant, positive correlations between the Trail Making Test Visual Scanning condition and the WMS-IV Verbal Paired Associates subtests (i.e., I and II).

Multiple significant, positive correlations between the Trail Making Test Number Sequencing condition and the WMS-IV subtests were indicated. A large effect size was indicated for the positive correlation between Number Sequencing and WMS-IV Verbal Paired Associates II. Medium effect sizes were indicated for the correlations between Number Sequencing and WMS-IV Visual Reproduction I, Verbal Paired Associates I, and Spatial Addition. A small effect size was indicated for the positive correlation between Number Sequencing and Logical Memory II.

Multiple significant, positive correlations between the Trail Making Test Letter Sequencing condition and WMS-IV subtests were also indicated. Medium effect sizes were indicated for the correlations between Letter Sequencing and WMS-IV Verbal Paired Associates

I and II, Designs I and II, Visual Reproduction I, and Spatial Addition. A small effect size was indicated for the positive correlation between Letter Sequencing and WMS-IV Visual Reproduction II.

Significant, positive correlations were also present between the Trail Making Test Letter-Number Sequencing condition and seven WMS-IV subtests. Medium effect sizes were indicated for the correlations between Letter-Number Sequencing and the WMS-IV Logical Memory II, Verbal Paired Associates I and II, and Designs I and II subtests, whereas small effect sizes were indicated for the correlations between Letter-Number Sequencing and WMS-IV Logical Memory I and Visual Reproduction I subtests.

A significant positive correlation was also indicated between the D-KEFS Trail Making Test Motor Speed condition and the WMS-IV Verbal Paired Associates II subtest. This correlation was small in nature with regards to effect size.

In addition, the D-KEFS Color-Word Interference Test Inhibition and Inhibition/Switching conditions were significantly correlated with two or more of the WMS-IV subtests. All statistically significant correlations were positive. The Color-Word Interference Test Inhibition condition was significantly correlated with two WMS-IV subtests. A medium effect size was indicated for the correlation between Inhibition and Verbal Paired Associates I; whereas a small effect size was indicated for the correlation between Inhibition and Visual Reproduction I.

The Color-Word Interference Test Inhibition/Switching condition was significantly correlated with multiple WMS-IV subtests. Medium effect sizes were indicated for the correlations between Inhibition/Switching and Verbal Paired Associates I, Designs I, and Visual

Reproduction I. A small effect size was indicated for the positive correlation between Inhibition/Switching and WMS-IV Visual Reproduction II. All remaining correlations between D-KEFS conditions and WMS-IV subtests were not statistically significant.

Table 7

Correlations between WMS-IV Subtest Scores and D-KEFS Condition Scores

Variable	Visual Scanning	Number Sequencing	Letter Sequencing	Number- Letter Switching	Motor Speed	Color Naming	Word Reading	Inhibition	Inhibition/ Switching
Logical Memory I	.084	.174	.029	.295*	.069	.072	.117	.103	.167
Logical Memory II	.125	.286*	.209	.344*	.074	.089	.223	.197	.227
Verbal Paired Associates I	.374**	.374**	.331*	.318*	.259	.205	.250	.312*	.313*
Verbal Paired Associates II	.425**	.516**	.469**	.473**	.287*	.044	-.044	.183	.210
Designs I	.180	.248	.399**	.351*	.255	.159	.046	.193	.307*
Designs II	.041	.135	.306*	.390**	.068	.050	-.023	.169	.215
Visual Reproduction I	.109	.304*	.380**	.292*	.157	.127	-.059	.286*	.309*
Visual Reproduction II	.064	.189	.279*	.230	.084	-.082	-.017	.146	.282*
Spatial Addition	.226	.378**	.396**	.254	.023	-.021	-.036	.010	.263
Symbol Span	.012	.093	.067	.188	-.102	.270	-.210	.187	.142

*Denotes significance at $p < .05$ **Denotes significance at $p < .01$

Statistical Assumptions

Data were evaluated to ensure assumptions necessary for canonical correlation analysis were met. First, all participants with missing data were removed from the dataset. The remaining data was examined for outliers using Mahalanobis Distance. That is, the distance between individual data points and the multivariate center was calculated and compared to χ^2 for $\alpha = 0.001$ and the number of variables in each analysis; using this criterion did not suggest the presence of any outliers for either dataset. Histograms, PP plots, and scatterplots of residuals were then used to evaluate normality, linearity, and homoscedasticity of the variable relationships. For variables used in Research Question #1 (i.e., What is the relationship between memory and executive functioning as measured by WMS-IV subtests and D-KEFS scores primarily associated with executive functioning [i.e., the Trail Making Test Number-Letter Switching condition and the Color-Word Interference Test Inhibition and Inhibition/Switching conditions]?), it was noted that there was a slight positive skew (see Figure 1). PP plots of the residuals suggested the data may be somewhat nonlinear; the width of the scatter did not suggest concerns for homoscedasticity (see Figures 2 and 3).

Figure 1

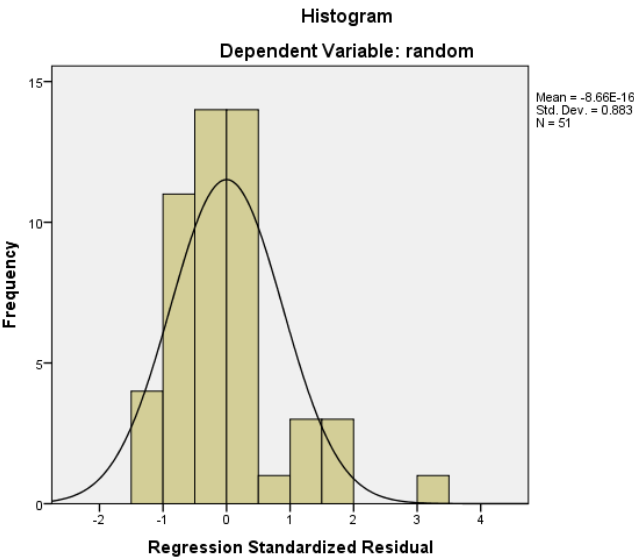


Figure 2

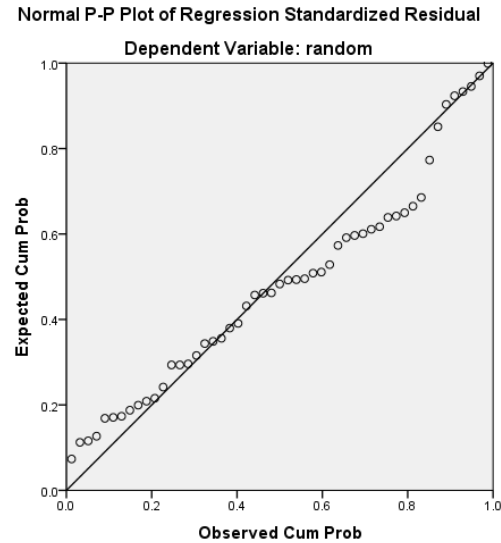
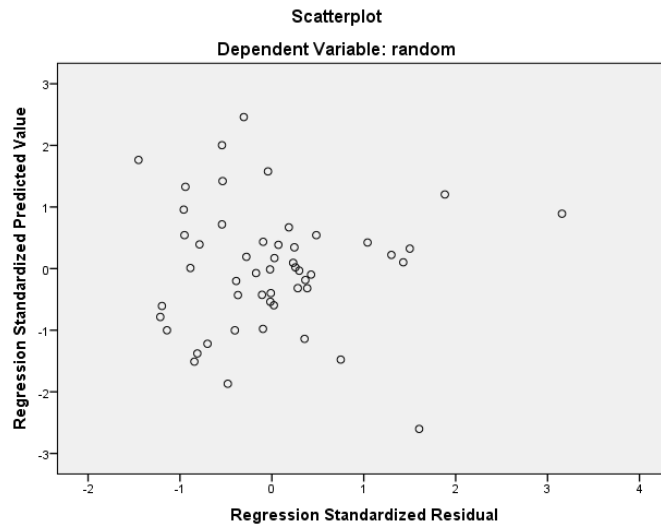


Figure 3



Similarly, histograms, QQ plots, and scatterplots of the residuals were used to evaluate normality of the variables used for Research Question #2 (What is the relationship between participants' performance on WMS-IV subtests and *all* conditions of the D-KEFS Trail Making Test and *all* conditions of the D-KEFS Color-Word Interference Test?). A histogram of standardized residuals for data to be analyzed for Research Question #2 suggested the data were relatively normally distributed (see Figure 4). QQ plots suggest evidence of possible nonlinearity (see Figure 5); the width of the scatter (see Figure 6) is not suggestive of problems with homoscedasticity.

Figure 4

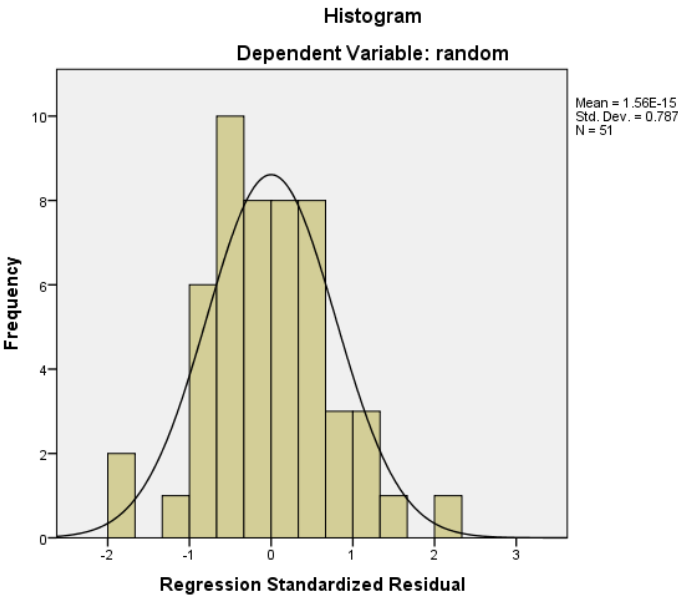


Figure 5

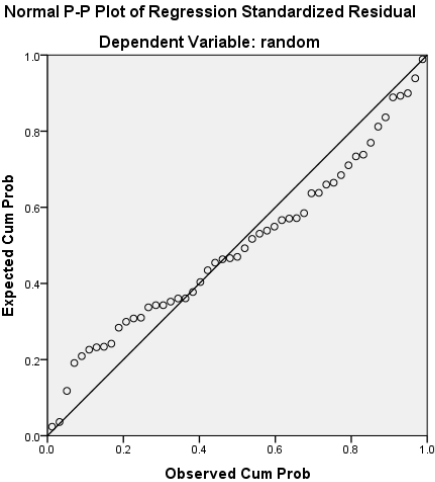
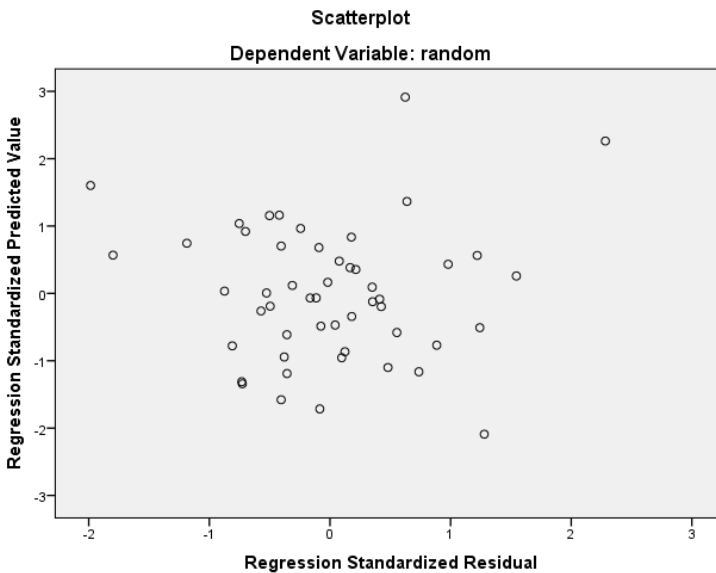


Figure 6



Canonical Correlation

Canonical correlation analysis was used to evaluate the strength and nature of the relationship between memory and executive functioning. This was accomplished by assessing the relationship between WMS-IV subtest scores and D-KEFS Trail Making Test and Color-Word Interference Test condition scores from a sample of undergraduate students. First, a canonical correlation analysis was conducted to answer Research Question #1:

R1. What is the relationship between memory and executive functioning as measured by WMS-IV subtests (i.e., Logical Memory I and II, Verbal Paired Associates I and II, Designs I and II, Visual Reproduction I and II, Spatial Addition, and Symbol Span) and D-KEFS scores primarily associated with executive functioning (i.e., the Trail Making Test Number-Letter Switching condition and the Color-Word Interference Test Inhibition and Inhibition/Switching conditions)?

This analysis yielded three canonical correlations, none of which were statistically

significant. The first canonical correlation relating the WMS-IV and D-KEFS scores (0.610) was not significant at a $p < 0.05$ level ($p = 0.253$). Similarly, the second canonical correlation relating WMS-IV and D-KEFS scores (0.448) was not significant ($p = 0.674$). The third canonical correlation relating WMS-IV and D-KEFS scores (0.339) was also not statistically significant ($p = 0.732$).

Next, canonical correlation analysis was used to answer Research Question #2:

R2. What is the relationship between participants' performance on WMS-IV subtests (i.e., Logical Memory I and II, Verbal Paired Associates I and II, Designs I and II, Visual Reproduction I and II, Spatial Addition, and Symbol Span), scaled scores on *all* conditions of the D-KEFS Trail Making Test (i.e., Visual Scanning, Number Sequencing, Letter Sequencing, Number-Letter Switching, and Motor Speed), and scaled scores on *all* conditions of the D-KEFS Color-Word Interference Test (i.e., Color Naming, Word Reading, Inhibition, and Inhibition/Switching)?

This analysis yielded nine canonical correlations, none of which were statistically significant. The first canonical correlation relating the WMS-IV and D-KEFS scores (0.751) was not statistically significant at a $p < 0.05$ level ($p = 0.201$). Similarly, the remaining canonical correlations were not statistically significant. The remaining eight canonical correlations and p -values were as follows: 0.667 ($p = 0.604$), 0.542 ($p = 0.855$), 0.476 ($p = 0.891$), 0.430 ($p = 0.890$), 0.359 ($p = 0.885$), 0.292 ($p = 0.838$), 0.263 ($p = 0.712$), and 0.146 ($p > .05$).

Summary

Overall, study participants demonstrated average performance (as defined by the test

manuals; Delis, Kaplan, & Kramer, 2001a; Wechsler, 2009a) on all subtests of the WMS-IV and all conditions of the D-KEFS Color-Word Interference Test and Trail Making Test.

Simple correlation analyses yielded multiple statistically significant correlations among WMS-IV subtests and D-KEFS Trail Making and Color-Word Interference Test conditions. The D-KEFS Trail Making Test Visual Scanning condition was positively correlated with the WMS-IV Verbal Paired Associates subtests, at a $<.01$ level of significance. The D-KEFS Trail Making Test Number Sequencing condition was positively correlated with WMS-IV Verbal Paired Associates I and II and Spatial Addition subtests at a $<.01$ level of significance and with Visual Reproduction I and Logical Memory II at a $<.05$ level of significance. The D-KEFS Trail Making Test Letter Sequencing condition was positively correlated with WMS-IV Verbal Paired Associates II, Designs I, Visual Reproduction I, and Spatial Addition at a $<.01$ level of significance and with Verbal Paired Associates I, Designs II, and Visual Reproduction II at a $<.05$ level of significance. The D-KEFS Trail Making Test Letter-Number Sequencing condition was positively correlated with WMS-IV Verbal Paired Associates II and Designs II subtests at a $<.01$ level of significance and with WMS-IV Logical Memory I and II, Verbal Paired Associates I, Designs I, and Visual Reproduction I subtests at a $<.05$ level of significance. Finally, the D-KEFS Trail Making Test Motor Speed condition was positively correlated with the WMS-IV Verbal Paired Associates II subtest at a $<.05$ level of significance.

The D-KEFS Color-Word Interference Test Color Naming and Word Reading conditions were not significantly correlated with any of the WMS-IV subtests. The D-KEFS Color Word Interference Test Inhibition condition was positively correlated with the WMS-IV Verbal Paired Associates I and Visual Reproduction I subtests at a $<.05$ level of significance. The D-KEFS

Color-Word Interference Test Inhibition/Switching condition was positively correlated with the WMS-IV Verbal Paired Associates I, Designs I, and Visual Reproduction I and II subtests at a $<.05$ level of significance.

Canonical correlation analyses, which were employed to assess the relationship between variable sets (i.e., subtest scores from the WMS-IV and condition scores from the D-KEFS tests) did not yield any statistically significant canonical correlations; therefore, analyses of correlations between each measure and overall canonical variates was not conducted.

CHAPTER V

DISCUSSION

This chapter is made up of five sections: (1) a summary of the study, (2) a discussion of the implications of the relationship between measures of memory and executive functioning in a sample of undergraduate students, (3) delimitations and limitations of the study, (4) directions for further research, and (5) conclusions.

Summary of the Study

The present study was designed to evaluate the canonical relationship between memory, as measured by the *Wechsler Memory Scale, Fourth Edition* (WMS-IV; Wechsler, 2009a) and executive functioning, as measured by selected tests from the *Delis-Kaplan Executive Function System* (D-KEFS; Delis et al., 2001a), in a college population. Specific types of memory evaluated in the current study included auditory memory, visual memory, visual working memory, immediate memory, and delayed memory. Specific types of executive functioning measured in the current study included inhibition and set shifting/task switching. The present study served to evaluate the relationships between memory and executive functioning as broad constructs as well as the relationships between more specific, subtest-level measures of memory and executive functioning. Implications of these relationships for theory and for the practice of neuropsychology were considered.

Participants were 51 college students (M age=20.21) enrolled at a large Midwestern university. All participants completed the WMS-IV in its entirety, which includes ten subtests: Logical Memory I, Logical Memory II, Verbal Paired Associates I, Verbal Paired Associates II, Designs I, Designs II, Visual Reproduction I, Visual Reproduction II, Spatial Addition, and

Symbol Span. All participants also completed the four conditions of the D-KEFS Color-Word Interference Test (i.e., Color Naming, Word Reading, Inhibition, and Inhibition/Switching) and the five conditions of the D-KEFS Trail Making Test (i.e., Visual Scanning, Number Sequencing, Letter Sequencing, Number-Letter Switching, and Motor Speed).

Scaled scores were calculated for each of the ten WMS-IV subtests and each condition of the D-KEFS Color-Word Interference Test and the D-KEFS Trail Making test. Scaled scores have a mean of 10 and a standard deviation of 3. For WMS-IV subtests, scores between 8 and 12 are considered to fall within an Average range. Similarly, for D-KEFS conditions, scores between 8 and 12 are considered to fall At Expected Level. Pearson product moment correlations were used to assess the relationship between each of the variables as measured by WMS-IV subtest scores and D-KEFS condition scores; then, canonical correlation analyses were used to evaluate the relationship between memory variables and executive functioning variables broadly.

For each WMS-IV subtest score and D-KEFS condition score, means and standard deviations were calculated for the sample group. All WMS-IV mean subtest scores for the participants fell within the Average range. Similarly, all D-KEFS condition mean scores for the participants fell At Expected Level. These results are slightly lower than expected for a sample of college students, whose performance on tests of memory and executive functioning would be expected to vary but generally fall within an Average to Above Average range (Davis, Pierson, & Finch, 2011; Ross, Poston, Rein, Salvatore, Wills, & York, 2016). Only 6% of WMS-IV subtest and D-KEFS conditions scores fell below the Average range. This is evidence that the study sample is not representative of the general population where a greater percentage of scores (i.e., 16%) would be expected to fall below the Average range. Similarly, the study sample is not

representative of many clinical populations. In clinical populations consisting of patients referred for known or suspected neurological problems, an even greater percentage of neurocognitive scores would be expected to fall outside the Average range.

Several statistically significant Pearson product moment correlations were found between WMS-IV subtest scores and conditions from the D-KEFS Trail Making Test. These correlations had small to medium effect sizes, with one exception. The Visual Scanning condition of the D-KEFS Trail Making Test was significantly correlated with two WMS-IV subtests (i.e., Verbal Paired Associates I and Verbal Paired Associates II). The Number Sequencing condition of the D-KEFS Trail Making Test was significantly correlated with five WMS-IV subtests (i.e., Logical Memory I, Verbal Paired Associates I, Verbal Paired Associates II, Visual Reproduction I, and Spatial Addition), and the Letter Sequencing condition of the D-KEFS Trail Making Test was significantly correlated with seven WMS-IV subtests (i.e., Verbal Paired Associates I, Verbal Paired Associates II, Designs I, Designs II, Visual Reproduction I, Visual Reproduction II, and Spatial Addition). The Number-Letter Switching condition of the D-KEFS Trail Making Test was significantly correlated with WMS-IV Logical Memory I, Logical Memory II, Verbal Paired Associates I, Verbal Paired Associates II, Designs I, Designs II, and Visual Reproduction I. The Motor Speed condition of the D-KEFS Trail Making Test was only significantly correlated with the WMS-IV Verbal Paired Associates subtest. The correlation between the D-KEFS Trail Making Test Number-Letter Switching condition and the WMS-IV Verbal Paired Associates II subtest was the only correlation with a large effect size.

Fewer statistically significant correlations were found between D-KEFS Color-Word Interference Test conditions and WMS-IV subtests. Statistically significant correlations were

only present between WMS-IV subtests and conditions of the D-KEFS Color-Word Interference Test associated with aspects of executive functioning. That is, the Inhibition condition of the D-KEFS Color-Word Interference Test was significantly correlated with the WMS-IV Verbal Paired Associates I subtest and the WMS-IV Visual Reproduction I subtest. The D-KEFS Color-Word Interference Test Inhibition/Switching condition was significantly correlated with four WMS-IV subtests (i.e., Verbal Paired Associates I, Designs I, Visual Reproduction I, and Visual Reproduction II).

Canonical correlation analyses were used to determine whether the relationship between a set of memory variables (i.e., WMS-IV subtest scores) and executive functioning variables (i.e., D-KEFS Color-Word Interference Test and Trail Making Test condition scores) was statistically significant. The first canonical correlation analysis was used to answer research question #1 (i.e., What is the relationship between memory and executive functioning as measured by WMS-IV subtests and D-KEFS scores primarily associated with executive functioning [i.e., the Trail Making Test Number-Letter Switching condition and the Color-Word Interference Test Inhibition and Inhibition/Switching conditions]?).

This analysis yielded no statistically significant canonical correlations between memory, as measured by the ten subtests of the WMS-IV, and executive functioning, as measured by three condition scores from the D-KEFS tests (i.e., D-KEFS Trail Making Test Condition 4 [Number-Letter Switching], D-KEFS Color-Word Interference Test Condition 3 [Inhibition] and Condition 4 [Inhibition/Switching]). Because a significant relationship between variable sets was not found, specific contributors to that relationship were not assessed.

The second canonical correlation analysis was used to examine the impact of additional

D-KEFS condition scores on the relationship; that is, what is the relationship between participants' performance on WMS-IV subtests (i.e., Logical Memory I, Logical Memory II, Verbal Paired Associates I, Verbal Paired Associates II, Designs I, Designs II, Visual Reproduction I, Visual Reproduction II, Spatial Addition, and Symbol Span), scaled scores on *all* conditions of the D-KEFS Trail Making Test (i.e., Visual Scanning, Number Sequencing, Letter Sequencing, Number-Letter Switching, and Motor Speed), and scaled scores on *all* conditions of the D-KEFS Color-Word Interference Test (i.e., Color Naming, Word Reading, Inhibition, and Inhibition/Switching)?

This analysis also did not yield any statistically significant canonical correlations between memory, as measured by the ten WMS-IV subtests, and the conditions of the D-KEFS Trail Making and Color-Word Interference tests. Taken together, results of these canonical correlation analyses do not suggest a statistically significant relationship between the broad constructs of memory and executive functioning; however, significant Pearson product moment correlations among WMS-IV subtest scores and D-KEFS condition scores suggest there are relationships between more specific measures of memory and executive functioning.

Discussion and Implications of the Relationship between Memory and Executive Functioning

Discussion

Results of previous research suggests there is a relationship between measures of memory and executive functioning (Vanderploeg, Schinka, & Retzlaff, 1994; Duff, Schoenberg, Scott, & Adams, 2005; Holdnack & Drozdick, 2009) although results may depend upon what measures are used. One study presented in the WMS-IV Technical Manual (Holdnack & Drozdick, 2009)

examined correlations between the WMS-IV and specific tests from the D-KEFS; two other studies used canonical correlation analyses to evaluate the relationship between measures of memory and executive functioning, among other constructs, and found shared variance (Vanderploeg, et al., 1994; Duff et al., 2005).

A study discussed in the WMS-IV Technical Manual (Holdnack & Drozdick, 2009), examined the relationship between aspects of memory and executive functioning as measured by the WMS-IV and the D-KEFS Trail Making and Verbal Fluency Tests. Results suggested weak to moderate relationships between WMS-IV subtests and conditions from the D-KEFS Trail Making and Verbal Fluency Tests. These results are consistent with results of the present study, in which correlations between the WMS-IV subtests and conditions from the D-KEFS Trail Making Test ranged from very weak to moderate.

A canonical correlation study by Vanderploeg and colleagues (1994) was designed to examine the relationship between auditory verbal learning as measured by the *California Verbal Learning Test* (CVLT, Delis et al, 1987) and executive functioning as measured by the *Wisconsin Card Sorting Test* (WCST; Heaton, 1981), the *Trail Making Test* (TMT; Reitan, 1958), the *Multilingual Aphasia Examination* (MAE; Benton & Hamsher, 1983), and the *Wechsler Adult Intelligence Scale-Revised* (WAIS-R, Wechsler, 1981). Results suggested measures of general verbal learning, working memory, and set shifting were the most important contributors to the overall relationship. Although a significant canonical correlation was not found between measures of memory and executive functioning in the present study, simple correlations between WMS-IV subtests and D-KEFS tests suggest there were statistically significant relationships between a measure of verbal learning (i.e., WMS-IV Verbal Paired

Associates I) and measures of set shifting (i.e., the D-KEFS Trail Making Test Number-Letter Switching condition and the D-KEFS Color-Word Interference Test Inhibition/Switching condition), $r=0.318$ ($p<0.05$) and $r=0.313$ ($p<0.05$) respectively. These results partially support Hypothesis I; that is, it was hypothesized that participants' performance on verbal memory subtests of the WMS-IV (e.g., Logical Memory I, Logical Memory II, Verbal Paired Associates I, and Verbal Paired Associates II) would be related to the D-KEFS Trail Making Test Number-Letter Switching and D-KEFS Color-Word Interference Inhibition and Inhibition/Switching conditions.

A canonical correlation study by Duff et al. (2005) was designed to evaluate potential overlap between measures of memory, learning, and executive functioning. Results of the Duff et al. (2005) study suggest a strong relationship between measures of executive functioning (i.e., the *Wisconsin Card Sorting Test* [WCST; Heaton, 1991], the *Halstead-Reitan Trail Making Test Part B* [TMT-B; Reitan & Wolfson, 1993], and the *Controlled Oral Word Association Test* [COWAT; Benton & Hamsher, 1989]) and measures of memory (i.e., the *Wechsler Memory Scale, Revised* [WMS-R; Wechsler, 1987], the *Rey-Osterreith Complex Figure Test* delayed recall condition [ROCFT; Rey, 1941], and the *Rey Auditory Verbal Learning Test* [RAVLT; Rey, 1941; Rey, 1964]). Specifically, Duff et al. (2005) concluded over 50% of the variance in measures of memory and executive functioning was shared; however, they noted that further research was necessary to better explain this relationship and posed several questions for further research. Two of the questions posed by the Duff research team were: "Which of these components [of executive functioning] impact memory performance, and to what degree?" (Duff et al., 2005, p. 121, and "Can the executive function components be partialled out of memory test

performance and used clinically" (Duff et al., 2005, p. 121)? The present study was designed to further explore the relationship between commonly used measures of memory and executive functioning. A key difference between the present study and the Duff et al. (2005) study is that the present study uses tests from the *Delis-Kaplan Executive Function System* (D-KEFS; Delis, Kaplan, & Kramer, 2001a), a newer executive functioning test battery which provides measures of component processes in addition to traditional measures of executive functions. Results of the present study did not suggest a significant canonical relationship between measures of memory and executive functioning (as measured by WMS-IV subtests and D-KEFS Trail Making Test and Color-Word Interference test conditions associated with executive functioning [i.e., the D-KEFS Trail Making Test Number-Letter Switching condition and the D-KEFS Color-Word Interference Test Inhibition condition and Inhibition/Switching condition]). The same was true of the relationship between measures of memory (as measured by WMS-IV subtests) and all conditions of the D-KEFS Trail Making Test and Color-Word Interference Test. In addition to the D-KEFS conditions associated with executive functioning, this second canonical correlation analysis included D-KEFS Trail Making Test and Color-Word Interference Test conditions designed to measure underlying or component skills of the executive functioning measures (e.g., visual scanning, number sequencing, letter sequencing, motor speed, color naming, word reading).

Although neither canonical correlation analysis yielded significant canonical relationships between the variable sets, simple correlations between WMS-IV subtests and D-KEFS Trail Making Test and Color-Word Interference Test conditions suggest statistically significant relationships exist between aspects of memory as measured by the WMS-IV subtests

and aspects of executive functioning and related component skills as measured by the D-KEFS condition scores. That is, although results of the present study do not suggest a statistically significant relationship between the *broad* constructs of memory and executive functioning in this sample (as evidenced by lack of statistically significant correlations between variable sets in both canonical correlation analyses), results do suggest significant relationships between more specific measures of components of memory and executive functioning (i.e., as described previously, there were statistically significant correlations among many WMS-IV subtests and D-KEFS condition scores). Generally speaking, this preliminary evidence regarding the relationship between memory and executive functioning in this sample speaks to the distinction between memory and executive functioning as *broad*, distinct constructs in a neurotypical population (i.e., there was not a significant degree of overlap or redundancy among memory and executive functioning variable sets). Results of the present study also speak to the divergent validity of the WMS-IV and the D-KEFS Trail Making Test and Color-Word Interference Test as measures of memory and executive functioning, respectively. That is, there was not a significant degree of overlap or redundancy among the sets WMS-IV subtests and D-KEFS conditions examined in the present study. Because the degree of shared variance between the WMS-IV subtests and conditions of the D-KEFS Trail Making Test and Color-Word Interference Test was not statistically significant, results of the current study suggest the WMS-IV and D-KEFS tests used in this study have adequate divergent validity. Nonetheless, as hypothesized, *aspects* of memory and executive functioning were found to be related in the current study. The strongest correlation found in the present study (i.e., the correlation between the WMS-IV Verbal Paired Associates II subtest, which measures delayed verbal non-contextual

recall, and the D-KEFS Trail Making Test Number-Letter Switching condition, which measures set-shifting or cognitive flexibility) is consistent with the results of past research which found measures of verbal learning and set shifting in particular were important contributors to the overall relationship between measures of memory and executive functioning. In addition, results of the present study are also consistent with results of the Holdnack and Drozdick (2009) study which found weak to moderate relationships between WMS-IV subtests and conditions of the D-KEFS Trail Making Test.

Although not consistent with the initial hypothesis (i.e., Hypothesis 2) that participants' performance on verbal memory subtests of the WMS-IV would be related to their performance on *all* conditions of the D-KEFS Color-Word Interference Test, results of the current study serve to extend the results of past research (i.e., the Holdnack and Drozdick [2009] study) by providing information about the relationship between the WMS-IV and the D-KEFS Color-Word Interference Test. As described above in relation to Hypothesis I, statistically significant correlations were found between the WMS-IV Verbal Paired Associates I subtest and conditions of the D-KEFS Color-Word Interference conditions intended to measure aspects of executive functioning (i.e., the Inhibition and Inhibition/Switching conditions).

The remaining hypotheses were also partially supported by results of simple correlation analyses. Hypothesis 3 (i.e., that participants' performance on WMS-IV visual memory subtests would be related to their performance on D-KEFS Trail Making and Color-Word Interference test conditions associated with executive functioning [the Trail Making Test Number-Letter Switching condition and the Color-Word Interference Inhibition and Inhibition/Switching conditions]) was partially supported. Participants' performance on the WMS-IV Designs I

subtest was significantly correlated with their performance on the D-KEFS Trail Making Test Number-Letter Switching condition ($r=.351, p<.05$) and the D-KEFS Color-Word Interference Test Inhibition/Switching condition ($r=.307, p<.05$), but not the D-KEFS Color-Word Interference Test Inhibition condition. Participants' performance on the WMS-IV Designs II subtest was significantly correlated with their performance on the D-KEFS Trail Making Test Number-Letter Switching condition ($r=.390, p<.01$), but not their performance on the D-KEFS Color-Word Interference Test Inhibition condition or Inhibition/Switching condition.

Performance on the WMS-IV Visual Reproduction I subtest was significantly correlated with all D-KEFS Test conditions associated with executive functioning at the $p<.05$ level, and participants' performance on WMS-IV Visual Reproduction II was significantly correlated with the D-KEFS Color-Word Interference Test Inhibition/Switching condition ($r=.282, p<.05$) but not the Inhibition condition or the D-KEFS Trail Making Test Number-Letter Switching condition. These results suggest there is a complex relationship between visual memory and executive functioning.

Hypothesis 4 (i.e., that participants' performance on WMS-IV visual memory subtests would be related to their performance on visually-based tasks from the D-KEFS Trail Making Test) was also partially supported. Participants' performance on the WMS-IV Designs I and Designs II subtests was significantly correlated with their performance on the D-KEFS Trail Making Test Letter Sequencing and Number-Letter Switching conditions, but not significantly related to their performance on other conditions of the D-KEFS Trail Making Test. Participants' performance on WMS-IV Visual Reproduction I was significantly correlated with their performance on all of the sequencing and switching aspects of the D-KEFS Trail Making Test

(i.e., Number Sequencing, Letter Sequencing, and Number-Letter Switching), whereas participants' performance on WMS-IV Visual Reproduction II was only significantly correlated with the D-KEFS Trail Making Test Letter Sequencing condition. Taken together, these results suggest visual memory is more closely related to sequencing and set-shifting than more basic visual functions (i.e., visual scanning and visuomotor speed).

Hypothesis 5 (i.e., that participants' performance on visual working memory subtests of the WMS-IV would be related to their performance on D-KEFS Trail Making Test and Color-Word Interference Tests associated with executive functioning [the Trail Making Test Number-Letter Switching condition and the Color-Word Interference Inhibition and Inhibition/Switching conditions]) was not supported. The only statistically significant correlations between WMS-IV visual working memory subtests and D-KEFS test conditions were between the WMS-IV Spatial Addition subtest and the D-KEFS Trail Making Test Number Sequencing condition ($r=.378$, $p<.01$) and Letter Sequencing condition ($r=.396$, $p<.01$). Contrary to initial hypotheses and results of past research which suggest working memory and executive functioning are highly correlated (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010), results of the present study do not suggest a significant relationship between visual working memory, as measured by the WMS-IV, and measures of executive functioning.

Overall, the findings that there were significant correlations between *individual* WMS-IV subtest and D-KEFS condition variables but not the *sets* of memory and executive functioning variables may suggest the relationship between measures of memory and executive functioning found in previous research may be explained by shared variance among specific types or aspects of memory and executive functioning rather than the broad constructs of memory and executive

functioning as a whole.

These findings fit well within the context of current understanding of the neuroanatomical correlates of memory and executive functioning. That is, memory consolidation is most often associated with the medial temporal cortex (Brown & Aggleton, 2001; Eichenbaum, 2004; Nyberg, 2008; Squire & Zola, 1996; Squire, 2009) whereas executive functioning is most often associated with the prefrontal cortex (Jurado & Rosselli, 2007; Nowrangi, Lysetkos, Rao, & Munro, 2014) and other structures with connections to the prefrontal cortex (Robinson, Calamia, Gläscher, Bruss, & Tranel, 2014; Tamnes, Østby, Walhovd, Westye, Due-Tønnessenb, and Fjell, 2010); however, there is some neuroanatomical overlap between aspects of memory and executive functioning. For example, the prefrontal cortex is thought to play a role in a variety of aspects of memory including encoding, consolidation, retrieval, and recognition of information (Stuss et al., 1994). Specifically, results of a PET study by Tulving et al. (1994) suggest the left prefrontal cortex is associated with encoding information into episodic memory, and the right prefrontal cortex is associated with retrieval of information from episodic memory. Also, the inferior medial frontal cortex and left dorsolateral prefrontal cortex have been shown to be associated with recognition of items from a verbal list learning task (Stuss et al., 1994). To summarize, this suggests areas of the prefrontal cortex, most often associated with executive functioning, may also be involved in key aspects of memory including encoding, retrieval, and recognition. In the context of the present study, this is particularly relevant to the relationship between the WMS-IV Verbal Paired Associates I subtest (i.e., a measure of verbal list learning) and measures of executive functioning from the D-KEFS Trail Making Test and Color Word Interference Test. Results of the present study suggest

a statistically significant relationship (i.e., $p < 0.05$) between WMS-IV Verbal Paired Associates I and all D-KEFS conditions designed to measure executive functioning (i.e., the D-KEFS Trail Making Test Number-Letter Switching condition, and the D-KEFS Color-Word Interference Test Inhibition condition and Inhibition/Switching condition). Participants' performance on these measures is likely correlated because of the neuroanatomical overlap known to exist for verbal list learning and executive functioning tasks.

Implications

Implications for theory and research. Given that the results of the current study were inconsistent with some results of past research which suggest a significant degree of shared variance between measures of memory and executive functioning, further research is needed to clarify the relationship in clinical and nonclinical populations. For example as described previously, Vanderploeg et al. (1994) studied the relationship between auditory verbal learning measures (i.e., the *California Verbal Learning Test* [CVLT; Delis, Kramer, Kaplan, & Ober, 2000]) and measures of executive functioning (i.e., the *Halstead Reitan Trail Making Test* [TMT; Reitan, 1958], the *Wisconsin Card Sorting Test* [WCST; Heaton, 1981], the *Multilingual Aphasia Examination* [MAE; Benton & Hamsher, 1983], and selected subtests [i.e., Digit Span, Similarities, Block Design] from the *Wechsler Adult Intelligence Scale, Revised* [WAIS-R, Wechsler, 1981], in a clinically-referred sample. Vanderploeg et al. (1984) noted that simple correlations between measures suggested a "minimal relationship" (p. 250) between CVLT index scores and the measures of executive functioning used in the study; however, there was a statistically significant canonical variate. Measures of verbal learning and proactive interference/working memory from the CVLT and measures of working memory (WAIS-R Digit

Span) and set shifting (*Halstead Reitan Trail Making Test*, Part B [TMT-B]) contributed most to the relationship. Vanderploeg et al. (1994) concluded that, "working memory and long-term memory are interdependent and that both are related to attention and mental tracking" (p. 251). In addition, results of the Vanderploeg et al. (1994) study suggest executive functioning, memory error types, learning strategies, and recall discrimination task performance were not significantly related. These results differ from results of the present study in that significant simple correlations between memory and executive functioning variables were found in the present study, but a statistically significant canonical variate was not found.

The Duff, Schoenberg, Scott, and Adams (2005) study, also described previously, further examined the relationship between memory and executive functioning in a clinically-referred sample. Measures of memory included subtests from the *Wechsler Memory Scale, Revised* (WMS-R; Wechsler, 1987) and memory conditions from the *Rey Auditory Verbal Learning Test* (RAVLT; Rey, 1941, 1964) and the *Rey-Osterreith Complex Figure Test* (ROCFT, Rey, 1941). Executive functioning measures included the *Halstead Reitan TMT-B* (Reitan, 1958), the WCST (Heaton, 1981), the *Controlled Oral Word Association Test* (COWAT; Benton & Hamsher, 1989), and the WAIS-R Similarities subtest (Wechsler, 1981). Results suggest a robust relationship between memory and executive functioning, which Duff et al. (2005) described as "consistent across both verbal and visual memory measures, and across indices of both immediate and delayed memory" (p. 119). In fact, some measures of executive functioning (e.g., the TMT-B) were found to be more strongly related to measures of memory than measures of other executive functions. Duff et al. (2005) surmised that the overlap between memory and executive functioning measures may be explained by a "superordinate cognitive function, like

intelligence" (p. 121), *or* it could be that there is too much overlap in currently available measures of memory and executive functioning. Another possibility is that memory and executive functioning are less related in nonclinical samples than in clinical samples. That is, perhaps results of the present study, which made use of a nonclinical sample, differ from past research which primarily relied on clinically-referred samples (e.g., Duff et al., 2005; Vanderploeg et al., 1994). The use of nonclinical samples, like the one used in the present study, is important because it promotes understanding of the relationship between constructs in a sample without known or suspected neurocognitive compromise; this gives researchers a point of comparison when studying the relationship between constructs in clinical populations.

For example, perhaps a significant level of shared variance between measures of memory and executive functioning was found in previous studies (e.g., Vanderploeg et al., 1994; Duff et al., 2005) because participants from clinical groups are more likely to demonstrate deficits in some other construct which then impacts higher order cognitive functions, like memory and executive functioning. One potential culprit could be inattention. Inattention is considered a primary soft sign of psychiatric and neurological dysfunction, and it can have a negative impact on individuals' ability to demonstrate more complex cognitive processes, like memory and executive functioning. If clinical populations demonstrate a greater degree of inattention, it is possible that this could depress their performance on measures of memory and executive functioning. A pattern of lower scores on measures of higher-order functions could make these measures seem more similar, statistically, in a clinical population. In a nonclinical population, we may see more typical levels of variance among neurocognitive functions. We might also expect less clinical levels of inattention and therefore greater variability in participants'

performance on measures of different neurocognitive functions. This may explain why measures of memory and executive functioning appear to be more distinct in the current study than in past research. Future research with both clinical and nonclinical populations could serve to further clarify the relationship between memory and executive functioning.

Implications for the practice of psychology. There is some degree of *neuroanatomical overlap* between memory and executive functioning (i.e., areas of the frontal lobe are involved in both executive functioning and memory). Results of past research and the present study suggest there is also some degree of overlap between confrontational measures of memory and executive functioning. However, results of the present study do not call the divergent validity of the WMS-IV and the D-KEFS Trail Making Test and Color-Word Interference Test vis-à-vis the overall constructs of memory and executive functioning into question because there was not a statistically significant degree of overlap between WMS-IV and D-KEFS variable sets. In the field of neuropsychology, evidence of adequate divergent validity is important to ensure assessments intended to measure different constructs do not inadvertently measure the same overarching construct. Measures with adequate divergent validity measure something unique. Divergent validity is particularly important for measures used clinically. If there was significant overlap or redundancy between the WMS-IV and the D-KEFS sets, they would not have been useful in differential diagnosis.

In addition to examining possible overlap between WMS-IV subtests and D-KEFS conditions as variable *sets*, correlations between the individual measures (i.e., subtests, conditions) which make up the WMS-IV and D-KEFS Trail Making Test and Color-Word Interference Test were examined. Although there were weak to moderate correlations between

individual WMS-IV subtests and D-KEFS conditions, they still have adequate specificity for use in differential diagnosis. WMS-IV subtest and D-KEFS condition scores were not so highly correlated to suggest that they are thought to be redundant, or measuring the same underlying constructs. This relates to the issue of test specificity. Tests with high specificity (i.e., tests that are targeted enough to measure a specific area of neurocognitive functioning) are important because they give clinicians the precision of measurement needed to identify particular areas of impairment.

In the field of neuropsychology, test specificity is important for differential diagnosis of a variety of conditions in both children and adults. Among other factors (e.g., a thorough clinical interview, records review, etc.), neuropsychologists rely on patterns of performance in a battery of neuropsychological assessments to help differentiate between diagnoses in question. They examine patients' strengths and weaknesses and compare them to known patterns of performance associated with diagnostic possibilities in question. For this process to be effective, it is important that measures used in neuropsychological evaluations have adequate specificity to determine precisely which neurocognitive abilities are intact and which are impaired. Only with specific and sensitive assessments with evidence of reliability and validity can clinicians have enough confidence in their interpretation of patients' patterns of performance to make appropriate diagnoses and treatment recommendations.

In children, measures of memory and executive dysfunction may help differentiate between acquired and developmental conditions such as attention-deficit/hyperactivity disorder (ADHD), autism spectrum disorder (ASD), and fetal alcohol spectrum disorders (FASD). That is, children with ADHD and ASD may demonstrate impairment in executive functioning (e.g.,

inhibition, cognitive flexibility, working memory, and vigilance; Corbett et al., 2009), whereas children with FASD often exhibit deficits in cognition-based executive functions (e.g., planning, set shifting, phonemic fluency), emotion-based executive functions (e.g., more variability in response-reward associations) and visual memory (Kodituwakku, Kalberg, & May, 2001). In addition to their utility in differential diagnosis of conditions like ADHD, ASD, and FASD, measures of memory and executive functioning are also important in determining or clarifying functional, academic, and other limitations of children and adolescents with other neurodevelopmental risk factors, such as preterm birth. For example, results of a study by Luu et al. (2010) suggest memory and executive functioning impairments may help to explain academic difficulties of adolescents born preterm.

In older adult populations, measures of memory and executive functioning can be used in the differential diagnosis normal aging vs. dementia. These measures can also be used to help differentiate between types of dementia. That is, whereas memory dysfunction is a hallmark symptom of dementia, certain types of dementia (e.g., frontotemporal dementia and vascular dementia) are also characterized by disproportionate impairment in executive dysfunction (Hornberger, Geng, & Hodges, 2011; Kramer, Reed, Mungas, Weiner, & Chiu, 2002; Massimo et al., 2009).

Test specificity is important for not only differential diagnosis but also for targeted treatment recommendations. Once patterns of performance are identified, neuropsychologists can recommend evidence-based interventions which are targeted for the unique needs of each patient. For example, if a child is referred for evaluation due to academic difficulties, but results of the neuropsychological evaluation suggest impairments in attention and executive functioning

are at the root of the academic difficulties, evidence-based interventions which aim to improve self-monitoring skills (coupled with academic accommodations) may be more appropriate for the student than interventions which target academic skill deficits alone. Similarly, if results of a neuropsychological evaluation suggest disproportionate impairment in reading and writing skills consistent with developmental dyslexia, evidence-based reading interventions targeted at the most basic reading skills not yet mastered would be more appropriate than an evidence-based intervention focused on self-monitoring.

Delimitations and Limitations of the Study

Delimitations

The current study served to replicate and extend the results of past research on the relationship between memory and executive functioning. Similar statistical analyses (i.e., canonical correlation analyses) were used to examine the relationship between measures of memory and executive functioning commonly used in the field of neuropsychology. However, the present study compares memory and executive functioning using updated measures commonly used by practicing neuropsychologists. For example, the present study used the newest available iteration of the *Wechsler Memory Scale* (i.e., the WMS-IV). The current study also used tests from the D-KEFS rather than other, older, stand-alone measures of executive functioning. The D-KEFS is a newer measure of executive functioning which utilizes the Boston process approach (Kaplan, 1988; Kaplan, 1990, Milberg, Hebben, & Kaplan, 1986). This approach allows for the consideration of participants' performance on component skills (e.g., naming, visual scanning, motor speed) thought to underlie performance on executive functioning tasks.

Another strength of the present study is that it uses a college population. Although Duff et al. (2005) suggested conducting further research with clinical populations, the use of nonclinical samples promotes understanding of constructs individuals without known neurocognitive dysfunction. As mentioned previously, this allows for comparison of neurocognitive constructs among clinical and nonclinical groups.

The use of canonical correlation analysis is a statistical strength of the present study. This multivariate analysis allows for the examination of sets of variables to determine whether they are independent. If significant canonical correlations exist, the analysis can also determine which variables contribute most to the overall relationship (Davis et al., 2011). This type of analysis was appropriate for the present study because it is an exploratory analysis that can evaluate research-based expectations.

Limitations

Although the present study extends our understanding of the relationship between memory and executive functioning, it is not without limitations that can be addressed in future research. One limitation of the present study is its limited sample size. Although data was originally collected from 68 participants, several participants had missing data and were removed from the dataset prior to statistical analysis. Although the sample size for the current study was adequate for the canonical correlation analyses, a larger sample size would have helped have helped increase statistical power, reduce the risk of type II error, and improve generalizability.

Another limitation associated with the study sample is that a convenience sample of college students was used. This sampling technique limits the generalizability of the study results to the larger population because the sample was limited in scope. Specifically, the sample for the

present study was limited in terms of age (age range = 18 to 26) and education level (i.e., all participants completed high school and were currently enrolled in college courses). It was also not completely representative of the general population in terms of gender (54.9% of the sample identified as female) or ethnicity (76.5% of the sample identified as Caucasian). Data from the 2010 United States census suggests 50.8% of the population identified as "female" (Howden & Meyer, 2011), and 72.4% of the population identifies as "White" (Humes, Jones, & Ramirez, 2011). Thus, the study sample has a slightly higher proportion of females and a slightly higher proportion of participants who identify as white/Caucasian than the United States population.

The present study would have benefited from clinical comparison groups. Although a nonclinical or neurotypical sample reduces the impact of potential confounding variables commonly associated with clinical groups (e.g., cognitive deficits associated with clinical diagnoses/referral concerns), it is nevertheless important to evaluate the relationship between neurocognitive constructs in clinical populations. This is particularly important because clinical populations made up of patients with known or suspected neurocognitive impairments are more representative of the patient populations seen by neuropsychologists. The sample utilized in the present study did include many participants with self-reported clinical diagnoses; however, it is still considered a nonclinical sample because the participants were not referred for clinical evaluation. In addition, the medical and psychiatric conditions reported by participants are not uncommon in the general population.

Another methodological limitation of the present study has to do with the limited scope of the executive function assessment. Because data was collected as part of a larger study, present study was limited to the measures used in the larger study, and only two of the nine

available D-KEFS tests were administered (i.e., the Trail Making Test and the Color-Word Interference Test). This limited the aspects of executive functioning evaluated for the purposes of this study to inhibition and set shifting. Other important aspects of executive functioning (e.g., planning, verbal fluency, self-regulation, etc.) were not evaluated and therefore their relationship with memory could not be assessed.

Directions for Further Research

Further exploration of the relationship between memory and executive functioning with clinical groups would provide additional insight into the relationship between these constructs with specific clinical diagnoses. It will be particularly important to evaluate the relationship between memory and executive functioning in clinical groups known to have higher rates of memory and/or executive dysfunction (e.g., children with attention-deficit/hyperactivity disorder, adults with traumatic brain injury, and older adults with dementia).

Future research may also expand the scope of executive functions assessed. As mentioned previously, only two of the nine tests of executive functioning available on the D-KEFS were included in the present study. Future research may utilize additional tests from the D-KEFS or other measures of executive functioning to help determine whether other aspects of executive functioning contribute to the relationship between memory and executive functioning.

In addition to the previously mentioned methodological changes that could further extend our understanding of the relationship between memory and executive functioning in clinical and nonclinical populations, future studies could also improve generalizability by increasing sample size and using alternate sampling methods to improve the representativeness of the study sample.

Conclusion

The present study was designed to evaluate the relationship between memory and executive functioning in a college sample. Results suggest specific aspects of memory and executive functioning (i.e., at the subtest- and condition-level) are weakly to moderately related. However, when examined together as sets, there is not a significant degree of shared variance among WMS-IV subtests and D-KEFS Trail Making Test and Color-Word Interference Test condition scores. This is inconsistent with results of previous research which suggest a significant degree of shared variance among measures of memory and executive functioning in clinical populations. Given the results of the present study, it is important that the relationship between measures of memory and executive functioning be examined further with both clinical and nonclinical populations. Further research may also better control for other variables (e.g., attention) which could mediate the relationship between memory and executive functioning in clinical vs. nonclinical populations.

Although the relationship between these constructs requires further evaluation, results of the current study *do not* suggest a level of shared variance among the WMS-IV and D-KEFS Trail Making Test and Color-Word Interference Test; that is, results of the present study do not call their divergent validity and utility for differential diagnosis into question. Reliable and valid measures of a variety of neurocognitive functions are necessary for comprehensive neuropsychological evaluations. Comprehensive evaluations which measure a variety of neurocognitive functions using reliable and valid measures allow neuropsychologists to use profile analysis to aid in differential diagnosis. It is important that the reliability and validity of measures used in these evaluations be established and maintained with each iteration.

DIVERGENT VALIDITY OF THE WMS-IV AND D-KEFS 100

Future research which takes the limitations of the present study into consideration and combats them may shed more light on the true relationship between memory and executive functioning as measured by currently available neuropsychological tests.

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